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EVALUATION OF THE FEASIBILITY AND ECONOMIC IMPLICATIONS
OF PRICING MECHANISMS IN SOLID WASTE MANAGEMENT

ABT Associates, Incorporated

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

As part of these activities, the study described here presents the results of an investigation of the economic and environmental implications of employing user charges for the collection and disposal of residential solid wastes.

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Director
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EVALUATION OF THE FEASIBILITY AND ECONOMIC
IMPLICATIONS OF PRICING MECHANISMS IN SOLID WASTE MANAGEMENT

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ABSTRACT

This study analyzes the potential of pricing mechanisms in solid waste management systems. Such pricing mechanisms have been suggested as appropriate means for encouraging greater efficiency of resource, both within the solid waste management system proper and among sources of solid wastes.

The study reviews the limited empirical evidence concerning supply and demand characteristics in markets for solid waste management (primarily collection) services. The analysis of processing and disposal and ancillary SWM services is hampered by the diversity of existing systems, and remaining problems in the conceptual clarification of the services provided.

The analysis of cost functions in the Collection and Transportation subsystem suggests that these cost functions are subject to variable returns to scale. For smaller communities, there are economies of scale with respect to the amount of waste handled. For larger communities, scale effects vanish.

The available literature provides sufficiently strong evidence for the importance of both prices (and pricing policies) and incomes as determinants of the amount of waste collected per household. This evidence is used in an exploratory numerical analysis employing decision-theoretic elements to assess the likely impact of pricing mechanisms. The analysis suggests that total system costs could be reduced through pricing mechanisms, even though there would be a tendency to rely more on self-disposal as prices for collection services increase.

The study concludes with a brief suggestion for a feasible method for implementing an effective pricing mechanism in SWM systems.

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SECTION I

CONCLUSIONS

With respect to supply patterns in markets for solid waste management services, three conclusions can be drawn from the review of the available evidence:

1. The cost of collection is almost completely determined by the amount of solid waste handled.
2. Collection frequency and pickup location modify the cost per unit of waste collected. Switching pickup location from the curb to the back of the house increases collection cost by 5-20 per cent. The evidence for collection frequency is inconclusive.
3. Aggregate cost studies for components of the SWM system other than collection and haul are required to complement available engineering cost studies.

Demand patterns for collection services are determined by the income of the household and the cost of collection to the household. The pricing policy of the SWM agency (explicit pricing vs. provision of unlimited services for a flat charge or under general-revenue financing) also appear to affect households' tendencies toward collection vs. self-disposal, e.g. through littering.

The available empirical evidence was used in a decision-theoretic analysis of the likely response of households to explicit pricing of SWM services. The results of this analysis suggest that total system costs would decrease as a result of lower waste generation rates, although the costs per ton handled would increase as a result of greater reliance on self-disposal.

SECTION II

RECOMMENDATIONS

The results of this study indicate that further research is required on aggregate cost functions in SWM system components other than collection and haul. In addition, more explicit recognition of managerial problems in solid waste handling is necessary, particularly in view of the scope of the available technology.

A major obstacle to an analysis of the impact of pricing mechanisms on solid waste generation patterns and quantities to be collected is the absence of data on waste generation. Unfortunately, there appears to be no feasible way to resolve this problem in a satisfactory manner, since waste generation data would have to be gathered on the spot -- a very expensive procedure that would also raise questions about the willingness of potential respondents to cooperate.

The only feasible means to assess the effects of pricing in an actual setting is therefore a combination of careful measurement of the amounts collected, as well as the observation of trends in littering and other violations of disposal ordinances. Such a combination could produce the empirical data in an experimental setting that are required to clarify some key management issues in solid waste handling.

Finally, the concentration of the current literature on the "hardware" components of the SWM system must be replaced by a more comprehensive view that includes all aspects of dealing with the problems of wastes, including the enforcement of disposal ordinances. The dearth of empirical material in this respect precludes a satisfactory solution to pressing management problems.

SECTION III

INTRODUCTION

PROBLEM STATEMENT

Solid waste management is one of the most important services provided directly or indirectly by the public sector. Its importance has grown rapidly in the recent past, primarily in response to three developments:

- sharp increases in the amounts of solid waste generated, both total and per capita, as a result of changes in production and consumption patterns;
- increasing commitment to the preservation of environmental resources which places a premium on methods of waste collection, processing and disposal that minimize environmental insults;
- the growing emphasis on the need to recover valuable materials and energy resources contained in the solid waste stream.

These developments have contributed to a greater complexity of the solid waste management problem. During the 1960's, the solution to management problems has been sought primarily in the development of new technologies for the collection of waste, volume reduction, resource recovery and disposal. The array of available technologies for solid waste management today is bewildering.

The rapid implementation of new approaches to coping with the solid waste problem, however, has been hampered by the lack of a simultaneous development of institutional and financial arrangements suitable for efficient procedures. Research into the managerial and economic aspects of solid waste management problems has lagged far behind the development of technical alternatives. These aspects have been approached largely ad hoc in the formulation of municipal and regional plans for solid waste management systems and procedures -- but without the results of comprehensive theoretical and empirical studies. The absence of such underpinnings may have constrained the development of more efficient systems.

One of the more prominent economic and managerial concepts discussed in the context of solid waste management problems has been that of prices or user charges for services provided. The argument for pricing solid waste management services is based on two major considerations. First, as in any market for goods and services provided by the public sector, some form of pricing would lead to a more efficient deployment of resources by providing immediate tangible feedback on consumer preferences and response patterns. Secondly, pricing SWM services would provide an incentive to the sources of waste to adopt less waste-intensive production and consumption patterns. Indirectly, such a system could therefore become an instrument for source reduction.

The basic argument for charging service fees in proportion to the amount and quality of SWM services consumed by the individual source is therefore quite pervasive. However, the application of the pricing concept in solid waste management systems raises a number of issues. These issues are partly practical and partly conceptual. The practical problems revolve primarily around the usual difficulties of measuring the output of a service industry. Conceptual issues concern the nature of collection, processing and disposal services. Because of the public health and resource conservation implications of SWM activities, the services provided cannot be treated as pure private goods. The typical SWM system supplies services directly to the private user by ridding him of a "bad" and eliminating the need for storage, transportation and disposal. SWM services also contain a strong public good component as a result of their importance in maintaining the environmental quality of the community which would be endangered by the uncontrolled and improper disposal by individual sources. This component satisfies the public good criterion: nobody can be excluded from the benefits of a cleaner environment.

These factors must be taken into consideration in the design of an efficient pricing system for SWM services. Traditionally, though, user charge mechanisms have been designed on the basis of the (assumed) ability to pay, and with primary emphasis on cost recovery implications.

This orientation has led to a situation in which the relatively widespread reliance on user charges by operating SWM systems may fail to produce the intended effects of pricing schemes. The present study reviews the available theoretical and empirical evidence to evaluate the potential for designing and implementing more efficient user charge systems. The study has been organized around the major information needs of such an assessment.

MAJOR RESEARCH ISSUES

At the conceptual level, three parties are involved in the market for SWM services: the supplier of these services, assumed to be a public agency providing these services directly or through a private contractor, the user of these services, sources that cannot find a buyer for materials that are regarded as a nuisance, and society as a whole which is affected by the public good element of SWM services. These three parties constitute the foci of the analysis here.

In terms of the supply side, the major research issues to be addressed can be summarized in terms of two questions:

- How can the outputs of the solid waste management system be measured adequately?
- What are the cost (or production) functions associated with these outputs?

Perhaps the most important question is the first one. As long as there is no suitable definition of output(s), the development of cost functions, a prerequisite for the analysis of possible pricing policies, is severely constrained. But the problem of defining outputs differs only in degree from the general problem of measuring production in the service industry.

The analysis of the relevant characteristics of the demand side is conceptually and empirically much more complex. The key issues arise from the fact that a given user of SWM services has the option to substitute

self-disposal for the consumption of SWM collection and disposal services. Since self-disposal methods are generally inadequate from an environmental point of view (backyard burning, dumping of waste on land or in water), such a substitution would raise the social costs of waste handling. The assessment of the degree of substitution resulting from explicit pricing of SWM services is hampered by the fact that the cost of self-disposal to the individual source cannot be determined with certainty. In addition to the direct and opportunity costs of self-disposal, there is also the possibility that self-disposal violates local ordinances. In this case, the possibility of fine payments must be included as a cost element. Its incidence depends on the probability of getting caught and convicted of the violation.

These considerations identify a number of issues that must be addressed in the analysis of the demand for SWM services. These issues can be summarized in terms of the following questions:

- What are the socioeconomic factors influencing the utilization of SWM collection and disposal services provided directly or indirectly by a public agency?
- What are the likely effects of an explicit pricing of SWM services on the generation of wastes?
- What are the likely effects of an explicit pricing of SWM services on the substitution of self-disposal for the utilization of collection and disposal services?
- What are the social costs of an increase in the incidence of self-disposal in terms of a degradation of environmental resources?

These questions must be analyzed by type of source. For example, self-disposal by residential sources of solid waste poses a problem different from self-disposal activities by institutional or industrial sources.

The analysis of the effects of pricing mechanisms in SWM systems on society as a whole is the crucial link in assessing the ultimate effectiveness of this potential management tool. The critical problem here is the measurement of the net benefits of a replacement of general

revenue financing or flat service charges by a more differentiated pricing system. Improvements in the efficiency of resource management generate social benefits. Costs arise from the resource requirements of the implementation of such a pricing mechanism, and the possible degradation of environmental resources as a result of increased reliance on self-disposal. Neither of these two components of the net benefit figure can be estimated reliably with available techniques. The analysis of these aspects therefore is explorative.

STUDY METHODOLOGY

The present study examines the major research issues surrounding pricing mechanisms in solid waste management systems by reviewing and synthesizing the available literature. In cases in which the literature simply does not exist, the approach consists in developing a conceptual framework for analysis and identifying the likely thrust of analytical findings through numerical examples.

In view of this approach, the results of the literature review have been integrated into the text, rather than being presented in a separate section. The structure of the presentation here reflects the structure of the research issues delineated above. The first section examines the supply of solid waste management services. The analysis is based on a simple distinction of two subsystems of the general SWM system, Collection and Transportation, and Processing and Disposal. The sources used include both economic studies of cost factors in solid waste management and engineering-type studies focusing on individual technical problems. The section concludes with an analysis of the implications of expanding the traditional view of SWM systems to include enforcement mechanisms for the protection of environmental resources against damages arising from inadequate disposal techniques.

The second section examines the behavior of the demand side. Data and research are much scarcer here than for the supply side. The discussion

begins with a review of the literature on the relationships between the characteristics of waste sources and their contribution to the total amounts of waste collected. It proceeds to the formulation of a general decision model that can be used to analyze the likely responses of the demand side of the introduction of explicit pricing systems for SWM services. A numerical version of this model, with crude estimates of the relevant parameters, is used to assess the likelihood of substitution of self-disposal for a utilization of SWM services. The resulting indications are integrated into the specification of a demand function for SWM services.

SECTION IV

SUPPLY OF SOLID WASTE MANAGEMENT SERVICES

INTRODUCTION

The major obstacle to a systematic analysis of supply -- as well as demand -- patterns in markets for solid waste management services is the diversity of existing systems. Public SWM systems vary widely with respect to the range of services provided. At one end of the spectrum, these services may be limited to the sale of disposal rights on publicly owned "sinks," such as landfills or ocean dumping grounds. At the other end, SWM systems may offer a complex array of services, including collection, haul, processing, resource recovery activities, and ultimate disposal of resources. In addition, the enforcement of anti-littering ordinances may also be viewed as a proper component of a comprehensive SWM system.

Differences in the range of services provided are often accompanied by differences in technical procedures and institutional arrangements used. For example, even in a relatively simple activity, such as collection, different methods may be used, such as direct-haul vs. transfer stations. Alternative institutional arrangements concern the degree to which public SWM systems transfer responsibilities to the private sector through contractual arrangements, and the geographic scope of the public system (regional vs. municipal). As a result of these differences, the determination of SWM service supply patterns for the "general" case is difficult.

The assessment of the potential of pricing mechanisms as a management tool in solid waste handling should have broad applicability, though. This requirement implies that a certain level of abstraction is needed. The analysis of cost factors in solid waste management as a basis for examining supply patterns therefore employs a simple two-component structure of a public SWM system, consisting of Collection and Transportation (C&T) and Processing and Disposal (P&D).

There is considerable evidence in the literature regarding cost factors in SWM systems. However, the systematic analysis and generalization of cost determinants is hampered by serious ambiguities concerning the measurement of the "quantities produced" by SWM subsystems. As in any other service industry, the definition of output is difficult; although SWM systems differ from pure service industries in the sense that they are handling a tangible material, qualitative differences remain a major factor. The analytical approach chosen here responds to this problem by focusing first on the definition of appropriate output indices that are subsequently used to organize the available cost information.

The data used in the -- necessarily crude -- empirical specification of cost functions for SWM systems have been culled from two types of sources. First, engineering-type studies of technical alternatives in the production of SWM services have examined the resource requirements of selected technologies as a basis for the estimation of unit costs. Technical alternatives examined in this manner include the routing of collection trucks by Bodner, Cassel and Andros [2], variations in the size of collection crews by Ralph Stone and Co. [18], and the comparison of direct-haul vs. transfer stations.

The second type of cost analysis for SWM systems concentrates on the determination of statistical regularities in relationships between system costs and output descriptors. This approach to the analysis of SWM costs is exemplified by the Hirsch study [13], and the economic portion of the University of California investigation [14].

COST RELATIONSHIPS IN COLLECTION TRANSPORTATION

The principal service provided by the Collection and Transportation subsystem is the pickup of the waste generated and stored by a given source, generally at periodic intervals, and its transportation to the processing or disposal site. The type of service is a private good, since exclusion is possible (and is common in privately operated collection operations). In addition, though, the output of Collection and Transportation includes also a significant externality element: disposal by each individual source,

or indefinite storage, is likely to violate environmentally sound solid waste management guidelines. By transferring solid waste from the private to the public domain under controlled conditions, the C&T subsystem therefore averts diseconomies in terms of environmental damages. These averted diseconomies become an additional output of Collection and Transportation.

The measurement of activity levels in the Collection and Transportation subsystem as a basis for identifying statistical regularities in cost relationships is hampered by the great diversity of the level and type of services provided. For example, collection may exclude certain types of waste, such as trash.

In view of these problems, the literature has focused on output indices that can be measured, even though they may not describe the full scope of C&T activities. Quantitative descriptors of service quantities deal with two major dimensions:

- amount of waste picked up over a given period of time;
- distance between source and disposal (or processing) site over which waste is transported.

In addition, there are two major qualitative factors that determine the amounts of services provided:

- frequency of pickup, for residential sources generally once or twice a week;*
- pickup location, either curbside or backyard for residential sources.

Any adequate descriptor of the service quantities produced by the Collection and Transportation subsystem must account for these four factors.

Gueron has suggested that such an output descriptor should be given in vector form to cover all the components of C&T services [9, pp. 177-179]. The output of the C&T subsystem for residential waste sources could then be written as:

* Pickup frequency is generally higher for industrial, commercial and institutional sources.

$$\underline{u} = (u_1, u_2, u_3, u_4) \quad (1)$$

where u_1 = amount of solid waste collected per unit time period;*

u_2 = distance over which waste is hauled to processing or disposal site;

u_3 = frequency of pickup;

u_4 = pickup location.

Measurement of the first two elements of the C&T output array can be made in conventional units (tons and miles/kilometers, respectively). Pickup frequency and location have generally been introduced into the costs analysis as dichotomous (0/1) variables. For example, frequency of pickup would be denoted by 0 for once-weekly, and 1 for twice-weekly; similarly, curbside pickup could be introduced as 0, backyard pickup as 1. The allowance for two options is sufficient in most instances. Greater differentiation could be achieved, but with corresponding increase in the complexity of the analysis. The discussion below illustrates the advantages of the restriction to two alternatives in each case.

The selection of specific elements as descriptors of the output of the Collection and Transportation subsystem allows for a derivation of an empirical cost function. Such a function can in turn be used to examine the cost recovery implications of alternative pricing schemes under consideration.

The literature fails to offer any examples of a comprehensive cost function that expresses total C&T costs as a function of the four output elements listed above. Generally, costs are expressed as a function of the total tonnage handled. The other elements are subsequently introduced as modifiers of the cost per ton. The major example for this approach is the University of California (UC) study. The empirical analysis discussed in the Final Report of that study [14] allows for a derivation of a general cost function.

* Volume of waste handled is frequently regarded as another important aspect of the total service output of the C&T subsystem. However, the predominant use of compactor trucks has narrowed the variability of the weight/volume ratios for different compositions of solid waste sufficiently to allow for a focus on weight only.

The central equation of the UC study expresses total cost of collection and transportation as a function of three types of factors: output, expressed as "annual tons entering the system" (corresponding to u_1); input prices, expressed as the monthly wage rate for collection labor; and operating conditions, expressed as the population density per acre. The last element can be regarded as a proxy for routing efficiency possible.

The empirical analysis of the postulated relationships based on data for 30 California municipalities yielded two results: First, the only significant variable in the cost equation was the output measure used (annual tons entering the system). Secondly, the coefficients of the log-linear equation used indicate that economies of scale depend upon the size of the population served. This second result is important, since it suggests that cost recovery implications of alternative pricing schemes may vary with the size of the SWM district. This possibility requires further analysis.

The log-linear regression equation obtained by the authors of the UC study shows the following parameter values:*

$$\ln C = -10.32 - 0.03 \ln \text{DENS} - \underline{.922} \ln \text{TONS} \quad (2)$$

where DENS = population density per acre;

TONS = annual tons entering the system.

The underlining of the coefficient of TONS indicates that it is significantly different from zero at the 95% confidence level. The magnitude of the coefficient of TONS implies moderate economies of scale overall. However, for cities with a population of less than 30,000, economies of scale are much more pronounced; for these cities, the coefficient of TONS drops to .635. As population size increases, scale effects become smaller. For cities with a population of more than 50,000, economies of scale are negligible, implying a coefficient of approximately 1. This evidence suggests that the C&T subsystem is subject to variable returns

* The notation used in this equation has been changed to differentiate it clearly from Equation (1) above.

to scale, depending on population size. Emerine [6] has derived the specific form of the cost function from a production function that exhibits variable returns to scale. The individual mathematical steps involved in this derivation are of minor interest in the present context. The final form of the cost function obtained can be used as a basis for specifying a comprehensive cost equation for the C&T subsystem.

This specification requires an examination of the quantitative impact of the other three output components listed in Equation (1) on total C&T costs. The distance factor can generally be treated in a straightforward manner. Average mileage charges, including labor, equipment depreciation, maintenance, fuel, etc., can be computed on the basis of accounting data. These charges can then be applied to total mileage traveled. The UC study used a cost factor of \$0.13 per ton-mile, based on data for Los Angeles City.

A possible problem in determining the cost impact of haul distance is the existence of two major technical alternatives, direct haul and the use of transfer stations. Engineering studies indicate that the relative advantage of one method over the other depends on the average distance between pickup and disposal sites. Direct haul is assumed to incur no fixed costs; for smaller distances, it is therefore less expensive than the transfer-station alternative. However, the greater incremental costs of direct-haul lead to a situation where the transfer-station method becomes preferable. Data for the Sanitation Districts of Los Angeles County illustrated graphically in Figure 1 suggest that the critical point is a distance of 20-25 miles -- corresponding to a round-trip driving time of approximately 100 minutes at 25 mph.

The comparison of the data reported in Figure 1 with the ton-mile cost factor of the UC study suggests care in using these average values. The total cost per trip is similar for both sets of data, between \$15 and \$16. However, since two different truck sizes have been assumed (5 vs. 8-ton capacity), the \$0.13 per ton-mile reported in the UC study are higher than the comparable figure for the data displayed in Figure 1. Total cost estimates may therefore differ substantially.

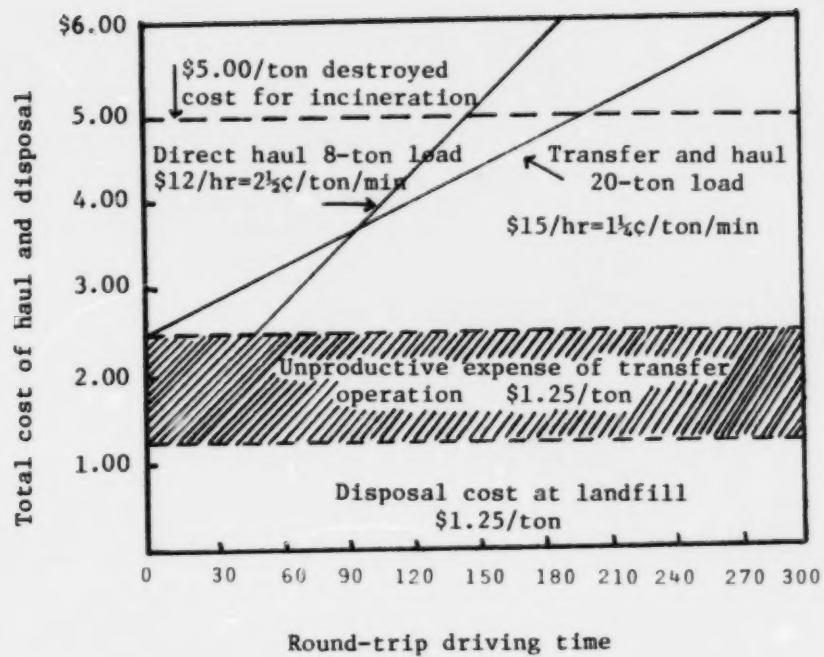


Figure 1. Direct Haul Vs. Transfer
Station Cost

Source: Salvato [17, p. 401]

The two qualitative factors, pickup frequency and pickup location, have been treated in C&T cost studies as dummy (0/1) variables, such that the higher-quality category (twice-weekly collection or backyard pickup) was coded as 1. It is reasonable to expect that the coefficient of these two dummy variables would be positive, i.e. that higher service quality increases cost per ton handled. With respect to pickup location, this hypothesis is supported by the available evidence. The UC study found that a switch from curbside to backyard pickup would increase average C&T cost per ton by as much as \$2.53 or 22%; the lower boundary of the estimated cost increase was \$0.51 or roughly 5%. Although the findings of the Hirsch study are not directly comparable, since he focuses on average annual cost per pickup, the general thrust remains similar. The estimated percentage increase associated with a switch from curbside to backyard pickup is approximately 30%. There are a number of possible explanations for the differences in the relative cost impact of changing pickup location. However, without further data gathering for confirmation, these explanations would have to remain sheer speculation.

The situation is even more problematic in the case of collection frequency. The UC study indicates that increasing collection frequency from once to twice weekly reduces average C&T cost per ton of solid waste handled by \$0.41 to \$0.84. This result is counterintuitive; the authors suggest that the provision of twice-weekly pickup services may be an indicator of an efficient SWM system, which recognizes the need for twice-weekly collection as a measure of rodent and insect control. Thus, lower per-ton cost and higher frequency of collection would be expressions of the same factor, system efficiency. As long as this factor cannot be defined more rigorously, an empirical test of the suggested explanation of the findings is clearly impossible.

The findings of the UC study are not supported by the results of the Hirsch investigation. Hirsch finds that switching from once to twice-weekly collection would increase C&T cost by approximately 20%. Thus, under the assumption of additivity, increasing service quality with respect to both frequency and pickup location might increase total C&T costs by as much as 50%, or even more in certain circumstances.

This information can now be summarized in form of a general cost function for the Collection and Transportation subsystem. Such a summary requires the assumption that the modifications to the basic equation expressing cost as a function of the amount (weight) of solid waste handled can be introduced in additive form. This assumption is appropriate for pickup location and frequency, since it is unlikely that either one of these two components is functionally related to the amount of waste collected.* However, the distance factor may be directly related to tonnage handled, since different amounts (and different collection densities) affect the choice of technology, such as crew size and vehicle capacity, which in turn affect the cost per ton-mile. For these reasons, the summary here employs the approach used in the UC study, that is, to include the distance factor directly in the amount/cost relationship.

Given this assumption, the overall cost function for the C&T subsystem can be written in general form as:

$$C(\underline{u}) = a_0 u_1^{a_1} + a_2 u_3 u_1 + a_3 u_4 u_1, \quad (3)$$

where u_1 = amount of solid waste collected per unit time period (year);

u_3 = 0 for once-weekly, 1 for twice-weekly pickup;

u_4 = 0 for curbside, 1 for backyard pickup;

a_i = coefficients ($i = 0, 1, 2, 3$); a_0 includes the effect of distance (u_3) on total cost.

The exponent of u_1 cannot be regarded as a constant. Rather, the available evidence suggests that a_1 is a function of the size of the population served by the system. It appears to approach 1, as the population served approaches 50,000.⁺ The other two coefficients assume a value that is likely to add 20 to 30 per cent to total costs, if either of the higher quality alternative is chosen.

* It is possible, though, that higher collection frequency increases the total amount of solid waste collected by providing fewer incentives to reduce waste generation.

⁺ This statement must be taken with a grain of salt, since the sample size and sample characteristics for the UC study fail to offer firm support for the findings of the study.

COST RELATIONSHIPS IN PROCESSING AND DISPOSAL

There have been virtually no economic cost studies for the Processing and Disposal subsystem. Considerable amounts of cost data derived from engineering studies are available; however, these cost studies are generally restricted to a particular technical alternative -- or used in the comparison of technical alternatives under "laboratory" conditions. In addition, we have survey-type data describing the range of actual expenditures on different elements and options in the P&D subsystem. The UC study [14] includes P&D costs as part of total system costs. However, the reported data indicate that approximately 92% of total SWM expenditures are accounted for by the C&T subsystem. This percentage appears abnormally high; in general, about 20% of total expenditures go to the P&D subsystem, if sanitary landfill is used alone. If incineration (with sanitary landfill for residues) is employed, the P&D percentage may go up to 40% of total system costs.*

The major problem for a comprehensive economic analysis of P&D costs is the diversity of technical alternatives either currently in use or in the late stages of development. This diversity precludes an accurate and generally applicable definition of service outputs. The technical alternatives include:

- sanitary landfill (or some other version of landfill);
- incineration;
- resource (including energy) recovery efforts;
- composting;
- pyrolysis;
- high-temperature combustion;
- wet oxidation;
- high-density compaction;
- any combination of the above.

This list is by no means exhaustive. But it indicates the range of technical options that have to be considered in the cost analysis.

* Data taken from Salvato [17, p. 397].

Conceivably, such a list could serve as a basis for identifying a comprehensive output vector for the P&D subsystem. The major components of this vector would be the positive externalities generated (or the negative externalities averted) by each option. This type of output measure can be illustrated by means of an example, focusing on a comparison of open dumps and sanitary landfill operations. Relative to the open-dump option, sanitary landfill operations can be described in terms of the following outputs:

- savings in volume/surface required resulting from proper compaction;
- reduction of air pollution associated with uncontrolled burning;
- reduction of health hazards by elimination of rodent breeding grounds and fly populations;
- reduction of olfactory insults;
- reduction of visual insults;
- reduction of leachate into groundwater supplies;
- allowance for reuse of land after completion of landfill operations.

These types of output measures can conceivably be quantified and used as a basis for estimating the social benefits of a switch from open dumps to sanitary landfill operations. This list could be extended to include the outputs generated by other technical alternatives, such as amounts of resources or energy recovered. A complete classification scheme is feasible, once a "no-action" alternative has been selected as a reference base; the one chosen here, open dumps, appears to be acceptable.

While the list of outputs can only be illustrative at this point, the examination of individual items suggests some of the difficulties that would be encountered in attempting to derive a general cost function for the P&D subsystem with any given specifications. The outputs listed cannot be regarded as independent of one another. For example, in the case of sanitary landfill, there exists a direct relationship between the reduction of olfactory insults and the reduction of health hazards due to rodents and insects breeding on the fill.

Functional relationships among different service outputs reflect the characteristics of the P&D technology employed by the SWM system. The definition of output categories, together with the identification of appropriate measurement techniques for each output, therefore would be insufficient to derive a general P&D cost function. Since technical choices affect the functional relationships among outputs, different cost functions would have to be derived for each technical alternative. However, the procedure suggested here would allow for a clear understanding of the relative advantages of alternative P&D technologies, given the costs of their implementation.

In view of these difficulties, the discussion here can focus on a few crude indicators of cost factors in Processing and Disposal only. Table 1 presents an overview of the cost ranges for various alternatives. The first column shows operating costs per ton of solid waste handled, while the second shows total capital value per ton capacity. The data provided fail to provide a clear assessment of actual unit system costs, partially because of differences in the reference base (throughput vs. capacity), partially since they refer to processes rather than installations. This type of cost information is therefore more illustrative than definitive.

Even so, available cost information can be used to derive a crude approximation of the P&D cost function that can serve as a basis for the numerical explorations of the implications of pricing SWM services in Section VI. The derivation of this function rests on the simple assumption that most of the environmental insults associated with solid waste processing and disposal are a direct function of the amount of solid waste disposed. A crude output measure for the processing component of the P&D subsystem is therefore the reduction of the solid waste stream achieved. Reduction can be measured either in terms of weight or in terms of volume. This consideration suggests a functional form of the P&D cost equation of the following type:

$$C(\underline{v}) = C(v_1, v_2) \quad (4)$$

Table 1. Solid Waste Handling and Disposal Costs

<u>Method</u>	<u>Cost in \$ per ton</u>	<u>Capital Cost \$ per ton</u>
Collection	10.00 to 13.00	-
Sanitary Landfill	0.75 to 2.50	8.00 to 14.00
Incineration	4.00 to 8.00	8,000 to 12,500
Composting	5.00 to 10.00	8,000 to 12,000
Pyrolizer	4.00 to 8.00	5,000 to 10,000
Transfer Station	1.00 to 2.00	1,000 to 1,500
Haul by trailer and sanitary landfill	3.50 to 6.00	-
Compact, bale, rail haul to sanitary landfill	4.00 to 6.00	-
Rural container station	7.00 to 10.00	-
Haul cost, 20-yd ³ compactor	0.20 to 0.25 per mi.	-
Compaction, rail haul, disposal to sanitary landfill	7.15 to 7.60	-
Compaction	1.00 to 1.35	9,000 to 12,000
Shredding	2.00 to 4.00	-
Shred, compact, bale	5.40 to 6.50	-
Barging to sea	4.00 to 6.00	-

Source: Salvato [17, p. 408]

where v_1 = difference between total amount of solid waste entering and leaving the system for final disposal;

v_2 = total amount of solid waste residues leaving the system for final disposal.

If these two components of the P&D output vector are measured in terms of weight, $v_1 = u_1 - v_2$; in that case, the cost function for the P&D subsystem would become a function of u_1 and v_2 only.

The use of this crude cost function can be illustrated by means of an example. Consider a system involving incineration and sanitary landfill of residues. Assume that about 25% of the collected solid waste are noncombustible (bulky items, construction wastes, street cleaning, etc.) and have to be separated from the waste stream. Assume furthermore that approximately 80% of the entering waste are "destroyed" by incineration. These assumptions, which are well within the ranges established by empirical studies,* yield the following breakdown of each ton entering the system:

Fraction "destroyed": 60 per cent;
fraction to be disposed: 40 per cent.

If the cost per ton destroyed is estimated at \$13, as suggested by Rogus [16], and the sanitary landfill cost is set at \$2 per ton processed, the resulting unit cost per ton entering the P&D subsystem would be:

$$\text{Unit cost} = C(\underline{v})/u_1 = 0.6 \times \$13 + 0.4 \times \$2 = \$8.60.$$

Such estimates can of course only be illustrative, since they are based on average data that are subject to measurement error and substantial variation. Even so, the use of crude estimates based on engineering-type studies and manufacturer's feasibility studies may provide a rough approximation that can be used in the analysis of the impact of pricing mechanisms on the market for SWM services. In the absence of reliable empirical data -- as well as the lack of a sound theoretical basis -- such order-of-magnitude estimates can provide valuable information.

* Cf. figures in Table 1; see also [17].

COST FACTORS IN ANCILLARY SERVICES

The traditional view of the solid waste problem has emphasized an engineering approach to the solution of these problems. Too little emphasis has been given to the managerial aspects. As a by-product of this orientation, ancillary services that are important in SWM systems have not been examined to the same extent as the "hardware components." These ancillary services include the actual management of the system, with its implications for institutional and financial arrangements, and the enforcement of ordinances and regulations against improper waste disposal methods. The present study examines one aspect of the management tools available. An extension to analyze alternative management structures of SWM systems would go beyond the scope of the investigation here.

However, the analysis of the enforcement system of regulations and ordinances against improper (self-)disposal is of critical importance for the assessment of the potential of pricing mechanisms in SWM systems. If the result of more explicit pricing of SWM services were in fact an increase in self-disposal, such as littering, dumping, backyard burning, and similar measures, as Gueron [9 , p. 297] has suggested, the enforcement system could play a significant role.

The review of the literature and the examination of a number of state and municipal SWM plans in the context of this investigation failed to yield any evidence on the level of enforcement activities in solid waste management. Generally, this aspect appears to be part of general law enforcement activities. There are some exceptions, of course. For example, the city of Boston employs several inspectors whose main function is the supervision of refuse storage facilities in the inner city. It is impossible, though, to generalize from such examples to the "typical" SWM system.

As a result, the impact of enforcement activities on the suspected increase in self-disposal resulting from the explicit pricing of SWM services cannot be examined on empirical grounds. The analysis in Section VI therefore employs a more normative approach.

SUMMARY

The analysis of the supply characteristics of solid waste management services based on the evidence reported in the literature leads to two major conclusions:

1. It is possible to determine an adequate set of service output descriptors for the Collection and Transportation subsystem, and to specify a rough empirical cost function that expresses costs as a function of these outputs.
2. The diversity of technical approaches used or feasible for the Processing and Disposal subsystem thus far has hampered the development of a service output taxonomy. The discussion in this section suggests a possible approach to establishing such a taxonomy. A simple alternative allows for the establishment of crude cost functions for alternative system specifications.

The available evidence indicates that the production of Collection and Transportation services is subject to increasing returns to scale, at least in sanitation districts with a population of less than 50,000. A similar pattern is likely to prevail in most types of Processing and Disposal systems, since the required capital installations are likely to be subject to economies of scale. As a result, marginal cost pricing would fail to recover total system costs.

SECTION V

DEMAND FOR SOLID WASTE MANAGEMENT SERVICES

INTRODUCTION

The analysis of the demand for solid waste management services lacks both an acceptable conceptual framework and an adequate empirical data base. Demand analysis has focused almost exclusively on Collection and Transportation services, treating the demand for other services, provided primarily by the Processing and Disposal system, largely as derived demand of marginal importance. Since pricing is used by SWM systems only in a limited form, the traditional concern of demand analysis, the determination of the relationship between the quantity demanded and the price of the good or service, cannot be addressed adequately. Finally, data limitations restrict the analysis almost completely to the quantities of waste collected, excluding the demand for SWM services associated with wastes not collected.

The empirical basis for an assessment of the effects of pricing on demand patterns for SWM services is therefore sketchy at best. Particularly one possibility, the substitution of self-disposal for collection* -- which has been suggested by Gueron [9], for example, as the major hazard of pricing SWM services -- has not been examined sufficiently to allow for an adequate assessment of the extent of such substitution effects. This section presents a review and summary of available empirical research. It is complemented in Section VI by a "quasi-empirical" analysis based on simulation experiments with a decision-theoretic model that enumerates the factors influencing the collection/self-disposal decision.

FACTORS INFLUENCING THE UTILIZATION OF COLLECTION SERVICES

The determinants of the utilization of collection services have been examined primarily in theoretical form in the literature. The standard

*Self-disposal is used here to denote socially unacceptable forms of disposal by the source, such as dumping at unauthorized sites, backyard burning, and littering.

version of the theoretical approach to this problem is Bonus [3], who expresses total demand for collection as the amount of waste generated. The amount of waste generated in turn is obtained as a linear function of the commodity bundle consumed. For each commodity, there exists a "waste coefficient" that specifies the amount of waste (given in weight or volume) per unit. Summing across all commodities consumed, the total amount of waste generated by the household can be determined. Such a simple linear model could be used to assess the impact of pricing on consumption patterns. The practical applicability of the model depends on the feasibility of a quantitative specification of waste coefficients. While such coefficients have been estimated for certain products, the problems involved in covering the complete range of consumption goods severely limit the usefulness of the model. These problems are compounded, once the model is expanded to include waste generated by industrial, institutional and commercial sources.

Similar reservations hold for the analysis presented by Gueron, [9] and [10]. While the approach to the demand analysis suggested by Gueron is theoretically consistent, its potential for application is limited. Its value as an instrument of examining the impact of pricing in a given SWM system is questionable.

In terms of residential demand for collection services, two studies provide useful empirical information on the socio-economic determinants of actual service utilization patterns. The University of California study [14] focuses on income and population density as demand-side characteristics, and a price proxy and household collection service policies as supply-side characteristics as determinants of the per-capita quantity of waste collected. A study of waste collection patterns in Chicago [4] provides a more differentiated analysis of the characteristics of households as determinants of amounts of waste collected. However, since this study focuses on a single SWM system, it does not allow for an assessment of the effects of system characteristics. These two studies form the core of the review in this section.

The UC study uses both total and household-only quantities of waste collected as a measure of the utilization of collection services. These measures are expressed on a per capita basis. The equation estimated expresses per capita amounts as a function of the average revenue of the SWM system (revenue/quantity collected) as a price proxy, per capita income, and population density:

$$w = f(x_1, x_2, x_3)$$

where w = total annual per capita quantity of (household) wastes collected in pounds;

x_1 = average (household) revenue, a price proxy;

x_2 = per capita income in service area;

x_3 = population density (population/square area).

A multiplicative specification of Equation (5) was used in log-linear form in the regression analysis for two sets of data, total per capita wastes and revenues, and per capita household wastes and household revenues. Both regression runs yielded similar results: the coefficient of the price proxy was significant at the 95% confidence level with a negative sign. The coefficient of population density was negative and significantly different from zero at the 95% (total) and 90% (household only) confidence levels, respectively. The coefficient of per capita income turned out to be insignificant in both regression equations. This result is puzzling in light of the findings of the Chicago study discussed below.

The interesting result is the responsiveness of the utilization of collection services to variations in the price of these services. For total wastes collected per capita, the price elasticity of demand was obtained as $-.704$; for households-only quantities, the price elasticity dropped to $-.455$. These results suggest that a 10% increase in the price of solid waste collection services will result in a 5-7% reduction of the quantity of wastes collected, other things being equal.*

* It should be noted that the price proxy does not refer to the price perceived by the household, since no SWM system in the analysis used pricing on a per-ton or per-pound basis. The findings therefore may conceal significant variations in the perceived price.

The authors of the UC study appear to accept these findings as evidence for the validity of the basic tenets of demand analysis in economic theory in the SWM service market. However, it is possible that this relationship should be attributed to other factors. For example, it is conceivable that inefficient SWM systems are inefficient both with respect to average cost, which requires higher average revenues, and service quality, which appears to lower the amount collected.* In this situation, average revenue and the per-capita quantity of waste collected would correlate negatively, since the first is a direct, the second an inverse expression of a lack of operating efficiency relative to the average. A number of other alternatives for explaining this relationship may exist. Thus, the interpretation of the findings of the analysis requires some caution.

Based on the interpretation of the estimated relationship between the price proxy and the extent of the utilization of collection services as a regular price elasticity, the authors of the UC study proceed to an analysis of the alternatives to collection: (1) reduce waste generation, or (2) use some form of self-disposal, such as dumping on vacant lots, street littering, or backyard burning. The first alternative is likely to produce a social net benefit, since it implies a more efficient use of materials. The second option is almost certain to generate high social costs, since the only alternative to the implied degradation of the environment is an effort to remove wastes from the public domain. Litter collection, however, is much more expensive than collection at the source; the UC study gives estimates of \$45/ton for street litter and \$13/ton for source collection -- implying a "social benefit" of \$32 per ton of a policy that discourages littering.

It is virtually impossible to determine whether households choose waste reduction or littering in response to higher prices for collection services. Since data on waste generation do not exist, the only viable approach to an empirical analysis of this issue is to relate the incidence of street litter to SWM pricing behavior. This is essentially the method used in the UC study. However, for reasons that are somewhat

* This interpretation is suggested by the UC study findings concerning the cost impact of collection frequency.

unclear, the price proxy of the demand equation is replaced by dichotomous (0/1) variables describing pricing behavior. SWM systems providing collection services without quantity limits at a flat rate charge to residential users (a zero marginal cost to the user) were classified as "internalizing." Systems with positive marginal prices (charges per can emptied) were categorized as "externalizing." These two categories were used in an analysis of total system costs, including street cleaning expenditures plus collection and haul cost for residential wastes. The analysis indicates that total system costs per capita in "internalizing" cities lie \$4.90 (or 35%) below those for "externalizing" cities, other things being equal. "Internalizing" SWM systems also showed lower quantities of street litter collected (a difference of 27%) and lower expenditures per capita on street litter collection (a difference of 36%), other things being equal. These results can be interpreted as -- somewhat circumstantial -- evidence for the generation of substantial social costs of explicit pricing in solid waste management systems.

This interpretation must be tempered by a number of considerations, though. In the first place, the analysis is not based on a rigorous and internally consistent conceptual framework. Secondly, the concepts that are introduced successively in the analysis are described only inadequately by the variables used. Thirdly, the sample sizes as well as the geographical restriction of the analysis raise certain questions about the degree to which these findings can be generalized.

The Chicago study [4] provides a more differentiated conceptual framework for the analysis of (demand-side) determinants of the amounts of residential wastes collected. The data refer to the 50 political wards of Chicago; they are weighted to adjust for the fact that the municipality accounts for only 50% of the total collected. Since the data describe weekly amounts collected, the investigators were able to consider seasonal variations in the analysis. The units of observation are all located in the same SWM system, so that the analysis of the determinants of the utilization of collection services was restricted to demand-side characteristics.

The analysis proceeded by listing three specifications of the general explanatory relationship:

$$w = f(z_1, z_2, z_3)$$

where w = weekly amount of solid waste collected from residential sources, either per dwelling unit or per capita (in pounds);

z_1 = median income;

z_2 = household size;

z_3 = race.

Other variables (such as variance of the income distribution) were also used in the analysis. The three functional specifications examined were the linear, the semi-log and the log-linear forms. The interpretation of the results with respect to the effect of income is based on the relative performance of these three functional forms, and the implied characteristics of the income elasticity. The linear form implies that the income elasticity increases with rising incomes. For the semi-log form, the reverse is true; the income elasticity is higher for lower incomes. Finally, in the case of the log-linear form, the income elasticity is constant.

The three functional forms were then applied to weekly collection data. The major finding of the study is that the amount of household refuse collected is highly sensitive to household incomes. Amounts of waste collected increase with increasing income levels. This finding of the Chicago study contrasts with the results of the UC study which found that per capita incomes had no effect on the per capita quantities of waste collected. A possible explanation for this difference lies in the nature of the income data used. Since the Chicago study used income data for wards, which can be regarded as relatively homogeneous with respect to socio-economic characteristics, the income variable is likely to be more descriptive in this situation. If per capita income figures for a whole city are used, as in the case of the UC study, significant intra-city variations may "average out", thus reducing the effect of the income variable on collection quantities. The income elasticity of the utilization of collection services varies with

the seasons, being relatively high in spring and fall, and almost insignificant in mid-summer.

In addition to determining a significant effect of the income variable, the Chicago study also found that the ethnic composition of households may affect quantities of waste collected; again, the influence of this factor depends on seasonal characteristics. It is strongest during the mid-summer months. A suggested explanation of the findings is that there exist two components of household waste: a "basic" component that remains constant throughout the year, and an "excess" component that varies according to seasonal patterns. This "excess" component reaches a minimum in mid-winter and maximum in mid-summer. The distinction between "basic" and "excess" wastes is supported by the relative performance of alternative forms (linear, semilog, and double log) of the regression equations used -- and the different behavior of elasticities implied -- for different seasons.

The Chicago study constitutes a good example for a comprehensive analysis of the demand-side determinants of amounts of waste to be collected within a given SWM system.* Such an analysis is essential in predicting variations in the solid waste stream to establish a basis for the efficient deployment of available resources. For the present analysis, though, the specific findings of the Chicago study are of limited usefulness, since they assume given system characteristics. Therefore, they fail to allow for an assessment of the response of quantities of wastes collected to alternative policies on the part of the SWM system. However, the distinction of "basic" and "excess" wastes, and the identification of seasonal variations in the "excess" component allow for a refinement of the assessment of the impact of pricing mechanisms on solid waste management systems.

Comparable studies concerning waste generation by sources other than households are rare. While some studies have been undertaken to determine per capita amounts of waste generated in industrial operations, e.g., within the framework of the University of California study [7, pp. 50-53], there have been few attempts to test any explanatory models.

* The report refers to waste generation, but data analyzed pertain to quantities collected.

One exception is a study of the determinants of waste generation patterns in commercial establishments in Greater Cincinnati by DeGeare and Ongerth [5]. Explanatory variables that showed significant regression coefficients were number of employees per store, number of hours open per week, and two dummy variables for type of store (drug and grocery stores). The results of this analysis are conceivably useful in projecting the total quantity of solid waste to be collected and processed in a given SWM system. However, these projections are subject to the same restrictions that have been mentioned with respect to the Chicago study of residential waste quantities: since the data were gathered within a given SWM system, they cannot be used to assess the responsiveness of the demand side to variations in system characteristics. Since the analysis in the present study focuses on residential demand for solid waste collection services, this lack of information is not a particular concern in this context. In general, though, the absence of adequate data and analytical findings regarding the behavior of waste sources other than households impairs the understanding of management issues in solid waste handling.

In summary, the empirical evidence concerning the determinants of the utilization patterns of collection services by residential waste sources indicates that characteristics of both households and the system exert a systematic influence on the quantities of waste collected. The findings of the UC study tend to support the hypothesis that agency pricing behavior influences the choice between collection and self-disposal options. SWM systems charging a non-zero marginal price for collection services, i.e. some form of user charge instead of a flat service charge or general revenue financing, tend to incur higher per capita costs for operating the system, once street cleaning is included. For systems with user-charge schemes, the proportion of street waste to waste collected also appears to be higher than in systems that provide unlimited services at zero additional cost to the user. The significance of these findings is difficult to assess in the light of crucial measurement problems.

Because of these problems, the available empirical evidence is insufficient to yield any insight into the effects of pricing of solid waste generation. The reduction of waste generation in response to pricing or

user charges must be treated as a theoretical possibility, although a priori considerations argue strongly in favor of such a source reduction effect. The Bonus model [3] is an attempt to explore such effects in a theoretical framework.

Somewhat surprisingly, the UC study found no relationship between quantities of solid waste collected from residential sources and proxies for household incomes. Aside from possible shortcomings in the analytical methods,* this finding may be attributable to the level of aggregation used. An investigation of more disaggregate data for political subdivisions of Chicago suggests a significant relationship between income and quantities of solid waste collected from household sources. This relationship appears to determine the amount of waste collected beyond a certain "basic" component; its importance is subject to seasonal fluctuations.

DEMAND FOR OTHER SWM SERVICES

The analysis of the demand for SWM services other than collection -- essentially all P&D services -- must distinguish two concepts of demand:

- the "social demand" for the level of P&D activities that determine the extent of environmental damages associated with a given amount of solid waste;
- the "private demand" for P&D services that results from the household's contribution to the total waste stream to be handled by the P&D subsystem, given some overall level of activity.

The first type of demand can be viewed as "demand" for a pure public good. It is impossible to exclude any given consumer from the benefits of proper disposal without damage to the environment or the results of resource/energy recovery efforts. Because of the public-good nature of these services, individual demand patterns cannot be established. The determination of socially desirable activity levels must rely on non-market mechanisms, such as voting, cost-benefit or project analysis, and similar techniques. An important input into the determination of desirable activity levels can be sketched in theoretical terms; its application in the planning and design of SWM policies, though, requires considerable efforts with respect to methodological development and data gathering.

* Generalized Least Squares (weighted regression) should have been used.

The core of this approach is a social damage function associated with alternative combinations of physical damages to the environment resulting from different approaches to Processing and Disposal activities. Conceptually, such a social damage function is a close relative of the social utility function of economic theory and planning. The derivation of this damage function for the P&D subsystem involves steps similar to the procedures suggested above for the definition of outputs of the subsystem. The first step consists in the development of an appropriate taxonomy of damages to environmental resources that are conceivably associated with the activities of the P&D subsystem:

- air pollution caused by components of the P&D subsystem as point sources (incinerators, open dump burning);
- water pollution attributable to spills, runoffs and leachate caused in the P&D subsystems;
- olfactory insults generated during processing and disposal operations;
- visual insults in the form of aesthetic degradation of existing landscapes in the process of disposal;*
- resource losses associated with the disposal of potentially useful materials;
- energy loss associated with the disposal of combustible or otherwise usable materials.

These categories are of course only illustrative of the elements that should be considered in the derivation of a social damage function for the Processing and Disposal subsystem.

Based on such a taxonomy of damages to the environment caused by alternative process options in the P&D subsystem, the social damage function could be developed in three steps:

- assessment of the physical impact on the environment in each of the categories specified for a given P&D process option;

* Proper sanitary landfill operations may in effect create "negative damages" or social benefits, if they are part of an organized land reclamation effort.

- translation of the physical impact into a social cost by monetizing losses incurred by individuals and by determining the number of people affected;
- summing across environmental impact categories to obtain a single numerical expression of the social cost of environmental damages associated with a given P&D process option.

Comparatively little research along these lines has been reported in the literature, at least with respect to solid waste handling. The situation is slightly different in regard to air and particularly water pollution. For example, the methodology of socioeconomic impact statements for wastewater treatment alternatives offers a pragmatic procedure for determining net changes in social damages for different strategies or technologies. Similar procedures could undoubtedly be used to derive empirical -- albeit crude -- estimates of social damages for alternative solid waste P&D technologies and effort levels. The development of these estimates could draw on the results of recent efforts to refine damage estimates by introducing risk factors to account for uncertainties in the specification of functional relationships (e.g., the damage to groundwater as a result of leachate).

The second type of demand for P&D services is generally a linear function of the amount of waste collected. In addition, the individual household also presents an effective demand for P&D services through littering. For a given P&D technology and effort level, the effective demand associated with a particular quantity of solid waste generated (both collected and littered) can be determined without difficulty, as long as solid waste is assumed to be a homogeneous material. Variations in demand patterns for a given quantity are associated with variations in the composition of solid waste. For example, separation by the household of certain items (paper, glass) may reduce the demand for separation services to be performed by the P&D subsystem. However, the general treatment of these qualitative variations, and the derivation of alternative demand schedules defy a systematic approach. These factors depend too much on specific characteristics of the P&D technology to allow for a comprehensive assessment in the framework of the present study.

In summary, the analysis of the demand for SWM services other than collection and haul faces two problems: (1) the complexity of system services provided, which place a premium on knowledge about the qualitative composition of waste collected as a determinant of individual demand for P&D services; and (2) the absence of relevant empirical studies of the demand patterns. As a result, the demand for P&D services (for a given technology and a given effort level or scope of operations) must be treated as a derived demand proportional to the total amount of solid waste generated by a given household.

SECTION VI

EXPLORATORY ANALYSIS OF PRICING IN SOLID WASTE MANAGEMENT

INTRODUCTION

The review of the available empirical evidence and the examination of relevant conceptual issues in the preceding two sections establishes a basis for an exploratory analysis of the impact of explicit pricing in solid waste management systems. The purpose of this analysis is twofold:

1. It is designed to provide some broad "quasi-empirical" guidelines for pricing solid waste management services, given limited information on actual behavior patterns.
2. It is geared toward identifying critical information needs that must be satisfied to develop an equitable and efficient pricing system.

The model of the solid waste management system used in this exploratory analysis is deliberately broad to include components that are normally treated as being of marginal interest to the solution of the waste problem. For example, recent textbook-type publications, such as [17] and [1], fail to treat street cleaning and enforcement of regulations against improper self-disposal as element of the SWM system. Such an oversight hampers the development of effective management systems for solid waste handling.

The analysis in this section proceeds by first describing a general model of the behavior of the household with respect to solid waste generation, utilization of collection/haul services, and self-disposal. This model is more comprehensive than any empirically testable version, since it focuses on waste generation for which no data exist. The discussion subsequently moves to the specification of a general model of the SWM system proper, which is assumed to consist of three subsystems, Collection and Transportation, Processing and Disposal, and Ancillary Services.

The generalized models of the behavior of the demand and supply sides are then used to assess the impact of explicit pricing mechanisms on waste

generation, total system costs, cost recovery patterns, and social costs arising from the degradation of the environment. To the extent possible, the findings of this "quasi-empirical analysis" are compared to actual patterns to reach a subjective assessment of the reliability of the conclusions reached.

A GENERALIZED MODEL OF RESIDENTIAL DEMAND FOR SWM SERVICES

As the discussion in the two preceding sections indicates, the demand for SWM services cannot be described in any given set of measures or indices. The demand model used in the simulation analysis therefore focuses on the generation of solid waste by residential sources as a basis for determining the demand for collection/haul and other services provided by the SWM system. A generally valid model describing the behavior of the household with respect to waste generation must incorporate both characteristics of the household and of the SWM system used. A broad formulation of this model can be stated as follows:

$$w^* = f(h_1, h_2, \dots, h_n; g_1, g_2, \dots, g_m) \quad (7)$$

where w^* = total amount of solid waste generated by the household over some unit time period (e.g. week or year);

h_i = household characteristics, such as household size, location (urban/suburban/rural), type of dwelling unit (single/multi-family), socio-economic characteristics;

g_i = SWM system characteristics, such as marginal cost of waste collected to the household, collection frequencies, pickup location, degree of enforcement of ordinances against self-disposal, and similar factors.

The application of this type of model in a "quasi-empirical" simulation analysis of the impact of pricing on the system as a whole requires the careful selection of a small number of significant variables that determine residential waste generation. The following paragraphs discuss the selection criteria and describe the variables used.

Household Characteristics

Income. The argument for introducing household income as a major determinant of residential waste generation rests on the assumption that wastes are by-products of consumption, which is almost completely determined by household income. The elasticity of waste generation with respect to income changes is therefore likely to be positive. Two considerations lead to the hypothesis that it is less than unity:

1. The marginal propensity to consume is less than unity; as income increases, the fraction consumed decreases, other things being equal.
2. Qualitative changes in consumption patterns conceivably lower the average "waste coefficient" of total consumption as income increases; higher income groups spend a higher proportion of their consumption expenditures on durable consumer goods and services.

The second argument cannot be regarded as a firmly established hypothesis. For example, an acceptable alternative states that higher incomes encourage a "throw-away" mentality, which would in fact raise the average "waste coefficient" of consumption. Without data on waste generation patterns, the relative merits of these two hypotheses cannot be tested.

The findings of the Chicago study support the statement that the elasticity of waste generation is less than unity; actual values vary between .3 and .7. These findings also indicate that the elasticity of waste generation increases with increasing income. However, the interpretation must account for the fact that the amounts of waste examined refer to waste collected. It is entirely possible that the apparent behavior of elasticities is biased by different patterns of the utilization of collection/haul services. For example, higher service quality leads to a higher utilization rate. Service quality is likely to be better in higher-income neighborhoods, if only because of better design of receptacles, better maintenance, and greater cleanliness of the area. Such differences may lead to a situation in which the higher-income areas make more intensive use of collection/haul services, which would be reflected in the imputed income elasticities.

Because of the uncertainties surrounding the behavior of the income elasticity over the relevant income ranges, the simulation analysis used an

exponential specification of the type $w^* = \alpha Y^\beta$, which implies a constant income elasticity of waste generation (β). This assumption is reasonable in a situation in which the direction of any possible relationship between the level of income and the waste generation/collection elasticity is unknown. The choice of parameter values is discussed below in the context of the specification of the complete demand model.

Family Size. Theoretically, the size of the household may affect waste generation in a number of ways. Generally, one would expect that a larger family size implies a higher fraction of total income spent on consumption, other things being equal. Higher consumption in turn would imply a higher ratio of waste generated to income. However, it is also possible that a larger family size for a given income level encourages greater efficiency in the use of consumption goods. In fact, the empirical evidence provided by the Chicago on household size is inconclusive. The explanatory power of household size is negligible; the regression coefficients are significant only for one of the weekly data sets. It is difficult to assess the significance of these findings, since only a linear specification of the regression equation is reported. Separate regression analysis runs with the data reported in the summary [4], discussed in Appendix C, yielded different results from those reported. The analysis here focused on the hypothesis that the effect of family size on waste generation (amount of waste collected) is interactive with family income. That is, the effect of family size depends on the income level. However, the tests of this hypothesis with data for two weeks and two years failed to yield significant improvements in the explanatory power of the income-household size model. The variable expressing the interaction of income and size (the product of these two variables) showed a significant regression coefficient in only one case, using generalized least squares.

These considerations and findings suggest that family size apparently is not a significant variable in explaining waste generation patterns. Even though this conclusion is questionable on theoretical grounds, the empirical analysis does not allow for an inclusion of household size as a determinant of waste generation. It is possible that this result can be attributed to the substitution of collection for generation data.

Type of Dwelling Unit. The type of dwelling unit occupied by the household can be a significant determinant of solid waste generation. On theoretical grounds, one would expect that families living in single-family units tend to generate higher amounts of waste, other things being equal. The waste volume is likely to increase as a result of garden wastes and other factors particular to the single-family dwelling. On the other hand, it is conceivable that some of the wastes can be reused (e.g. in composting). However, given the relatively low acceptance of reuse efforts, the additional sources of waste within the single-family unit household are likely to outweigh counterforces.

The empirical evidence on this factor is extremely limited. The UC study presents estimates of 1.429 tons per year for single and .628 tons per year for multi-family units. In other words, the average amount per household in single-family dwellings is more than twice the amount for multiple-family units. However, these averages fail to account for the influence of differences in family size, income levels and related consumption patterns, and other systematic distinctions between households in the two types of dwelling units. Unless it is possible to control for the effects of these factors, observed averages are likely to overstate the influence of different living patterns substantially. Because of the uncertainties associated with available empirical estimates, the simulation neglects type of dwelling unit as an independent variable.

Other Factors. Other factors that could be considered include the location of the household, e.g. urban, suburban and rural. Again, though available empirical material does not allow for an assessment of the influence of the location factor independent of other elements that may be systematically related to location.

With the exception of the race variable in the Chicago study, possibly relevant socioeconomic variables, such as education, have not been studied as determinants of waste generation (or amounts of waste collected). It is therefore impossible to use these factors in any but the most conjectural analysis of the possible impact of pricing mechanisms in solid waste management systems. Similar reservations hold for other household variables.

System Characteristics

Price of Collection Services. The findings of the UC study indicate that the most important variable for explaining the amounts of solid waste collected is the price of collection services (or the pricing policy pursued by the SWM system). The problem with handling price in a simulation of actual operating conditions is the basis upon which prices are charged. The price proxies used in the UC study were computed by dividing total (household) revenue by total amounts of (household) wastes handled. This measure does not constitute a "price" in the sense that it is used in the analysis of supply and demand in other markets. But it is likely to be the only way to estimate the cost to waste sources on a per-ton (or per-pound) basis.

The analysis of existing user charge systems fails to offer a resolution of this issue. Among the 50% of all municipal SWM systems that employed some form of user charge system in 1968, practically all were charging for container capacity (a fee per can). In other words, collection user charges currently in use refer to waste volume rather than weight. In spite of this situation, the simulation examines price on a weight basis. There are two reasons for this procedure. In the first place, the discussion in Section IV shows that weight is a better descriptor of service levels, particularly in view of the growing importance of compactor trucks in collection. Secondly, it is possible to compute weight/volume conversion factors for different types of solid waste, so that price per ton or pound can be translated into price per volume, albeit with a considerable margin of uncertainty.

The derivation of relevant price ranges will reflect the specifications of the supply model discussed below.

"Price" of Self-Disposal. In the same way that the price of collection services is an important determinant of their utilization, the "utilization" of self-disposal as a means to transfer waste from the private into the public domain is determined by its "price" or marginal cost to the consumer. The determination of the marginal cost is extremely difficult.

Its conceptual clarification is critical, though, to an adequate treatment of the impact of pricing and related policy measures on the SWM system. This "price" can be derived by examining the total cost of self-disposal to the household.

This cost is made up of three components. First, there is the direct cost of self-disposal, consisting of the value of time spent on transporting the waste to the disposal site, or on supervising backyard burning, or any other activity involved. It also includes the cost of any material used in self-disposal. The second component is the expected cost of any fines that may be incurred as a result of violating municipal ordinances against littering or backyard burning. This cost component is subject to policy manipulation to some extent. Finally, the cost of self-disposal may include some allowance for a reduced welfare of the household resulting from deteriorations of the physical and social environment. This last cost component is largely random, depending on the characteristics of the situation and the self-disposal method used.

The simulation analysis assumes that both the direct cost and the cost of reduced welfare can be handled on a per-unit basis as constants. The major variable element is the expected cost of self-disposal because of fines for violating local disposal ordinances. In its most rudimentary form, this cost over some period of time (year, month or week) is simply the expected value of fines:

$$E(F) = \sum p_n F_n, \quad (8)$$

where p_n = the probability of receiving n fines over some specified time period;

F_n = the total dollar cost of n fines.

Generally, the fine schedule for violations of waste disposal ordinances is given for a given community. For example, any littering or backyard burning may be subject to a fine of up to \$50 (or \$100). The actual fine often depends on the severity of the violation, and the number of times an individual (or household) has been subject to prosecution. Because of the large number of intangibles that affect the actual assessment of fines,

schedules would require that a given amount of solid waste over some time period be translated into a number of discrete actions. Finally, it is unclear to what extent households are actually aware of any existing fine schedules. For these reasons, a different approach has been chosen here. The expectations of the household concerning the cost of self-disposal are expressed in terms of a subjective probability distribution; the average fine (mean of the distribution) and its variance (a proxy for risk) are functions of the fraction of total waste generated that is transferred to the public domain through self-disposal. For a given fine schedule, and given level of effort to enforce disposal ordinances, we therefore have the following relationships:

$$\begin{aligned}\mu_F &= f(\lambda), \\ \sigma_F &= g(\lambda),\end{aligned}\tag{9}$$

where μ_F = mean of the subjective fine probability expectation function (\$);

σ_F = its standard deviation (\$);

λ = the fraction of total waste generated that is self-disposed.

Once the functional relationships between the fraction of total waste generated that is self-disposed and the parameter of the fine expectation function have been determined, the analysis can use established procedures of decision analytic research to determine the behavior of the household.

For the fine expectation function itself, it is likely that both the mean and the variance increase with increasing λ . The greater the amount of solid waste self-disposed, the greater the probability of receiving a (higher) fine. This specification can be regarded as generally acceptable. The situation is slightly more complicated with respect to the variance (or risk). It is reasonable to expect that the risk increases, as the exposure increases with increasing amounts of solid waste self-disposed. However, if the variance is strictly interpreted as uncertainty, the opposite relationship may apply. As the fraction of total waste self-disposed increases, total fines may be known with greater certainty. In that case,

the assumption of a discrete fine schedule below is replaced by a more flexible formulation, referring to the range of fines perceived by the household as being potentially relevant. Further research would be required to provide the necessary empirical basis for this aspect. For the purposes of the analysis here, though, greater flexibility is an asset, since fine schedules and their perception by the individual household may be important policy variables for the SWM system. While the extent and accuracy of households' perceptions can only be influenced, e.g., through public education efforts, the fine schedule itself is completely controlled by the SWM policy maker.

The perceived probability of receiving a given fine depends on the amount of solid waste transferred to the public domain through self-disposal, and the efforts of the SWM system to enforce disposal ordinances. The SWM decision maker can increase the probabilities for any given behavior pattern of the household, and thereby its expected fine, by:

- hiring special inspectors full-time concerned with the detection of violation of disposal regulations;
- increasing the awareness and concern of the local police for the importance of enforcing disposal regulations;
- increasing the willingness of the enforcement system to assess fines for given violations.

Unfortunately, there are no clear theoretical relationships between these efforts and changes in fine probabilities for a given behavior pattern of the household. In the analysis here, no effort will be made to relate these policy actions to variations in probabilities. Rather, the analysis focuses on the effects of increases in fine probabilities on the impact of pricing in SWM systems; the implied SWM efforts are discussed only in a qualitative sense.

The introduction of expected cost into the analysis calls for a refinement of the discrete formulation of Equation (8). Since fines may vary (almost all ordinances examined call for fines up to some amount), the determination of the number of fines received fails to allow for a direct assessment of the associated dollar cost. In addition, the use of discrete fine

schedules would require the translation of the fraction of total waste self-disposed (λ) into a number of separate "littering trips." This type of translation introduces a degree of rigidity into the analysis, which is neither necessary nor intuitively acceptable. An alternative to this approach is a decision-theoretic framework which examines the household's behavior under uncertainty concerning the cost of self-disposal. The specification of the decision-theoretic approach here follows the presentation in standard textbooks, such as Halter and Dean [11].

The key assumption of the decision-theoretic framework is that the household attempts to maximize some utility associated with the "net income" obtained after subtracting the cost of waste transfer to the public domain. This net income is given by

$$y = Y - p_C(1 - \lambda)w^* - g(\lambda w^*) \quad (10)$$

where y = net income of the household after the cost of transferring waste to the public domain has been accounted for;

Y = gross income of the household;

p_C = the price (marginal cost to the household) of collection services;

λ = the fraction of total waste generated that is self-disposed;

w^* = the total amount of solid waste generated by the household;

$g(.)$ = the cost function (fine schedule) for self-disposal, a random variable with mean μ_F and standard deviation σ_F , as described in Equation (9).

Associated with this net income function is a utility function which reflects both preferences for the level of net income and the associated risk.* Under the assumption that most household will exhibit risk-averse behavior with respect to self-disposal, an appropriate specification of this utility function is the logarithmic form, i.e. $U = \ln y$. The household chooses λ so as to maximize the expected utility. A Taylor series expansion of the utility function (see Appendix B for the mathematical

* The utility function in a decision-theoretic context describes tradeoffs between expected values and risk; it is not the ordinal utility concept of microeconomic theory.

detail) yields the following expression for expected utilities:

$$E[U] = U(\mu_y) - \frac{\sigma_y^2}{2\mu_y^2} \quad (11)$$

where μ_y = expected net income;

σ_y^2 = variance of the income expectation function.

Given the relationships between the expected value and the variance of the net income function and the corresponding parameter of the fine expectation function, it is possible to express $E[U]$ as a function of λ . This specification allows for a direct determination of the total and marginal cost of transferring solid wastes generated by the household to the public domain. The discussion below uses the approach summarized here in a numerical exploration of the impact of pricing.

Other System Characteristics. The UC study suggests that frequency of collection and pickup location may have some effect on waste generation patterns. On theoretical grounds, it appears reasonable to expect that higher collection frequency tends to encourage waste generation to some extent, since storage requirements for the household are reduced, thus lowering the cost of waste generation. With respect to pickup location, theoretical constructs linking this service to waste generation patterns are rather tenuous. The only relevant variable therefore would be collection frequency.

However, its introduction into a general model of waste generation is difficult, since the California data fail to control sufficiently for other characteristics. For example, the possibility of some confounding relationship between income and collection frequency cannot be excluded. This factor therefore could not be used in the exploratory simulation analysis of the impact of pricing in solid waste management systems.

It is also possible that there exist other system characteristics (e.g. a requirement for separation of wastes) that would affect waste generation patterns. Unfortunately, the empirical data describing the impact of such measures are lacking.

Summary: The Residential Waste Generation Model

The discussion in this subsection has identified two factors that are significant in determining the amount of solid waste generated by a given household, income and the marginal cost of transferring solid wastes to the public domain (a generalized price variable). The analysis shows that the price variable is not determined independently of the individual household, since it depends on the fraction of total waste generating transferred to the public domain through some form of self-disposal.

The waste generation and allocation model derived for the exploratory analysis can be summarized in the following form:

$$w^* = f(Y, p^*) \quad (12)$$

where p^* denotes the marginal cost of transferring solid wastes to the public domain. This variable in turn is a function of the allocation of wastes between collection and self-disposal:

$$p^* = h(\lambda) \quad (13)$$

where the fraction going to self-disposal (λ) is chosen so as to maximize the expected utility associated with income net of transfer costs and the risk connected with self-disposal.

This summary statement provides the framework for the specification of functional forms and the determination of relevant parameter estimates below.

A GENERALIZED MODEL OF THE SUPPLY OF SWM SERVICES

The discussion of supply characteristics in markets for SWM services in Section IV illustrates some of the problems associated with the conceptual clarification and empirical specification of relevant cost relationships. The principal idea behind user charge or pricing systems for SWM markets, in addition to greater equity in the allocation of costs among generators of solid waste, is increased efficiency in the use of all resources (source reduction effects) and in the use of resources in the collection and dis-

posal of wastes without damage to the environment. However, even if complete data were available on cost factors and unit costs -- which can be viewed as efficiency indices -- the large number of technical options and their complexity makes the pricing of disposal services extremely difficult to handle. The analysis of cost structures and appropriate pricing procedures for disposal services would have to account for factors such as the composition of solid waste collected (e.g., all wastes vs. non-garbage wastes), the disposal technology used, and the institutional/managerial arrangement (e.g., regional vs. municipal). Because of this great variability, the analysis of pricing disposal services requires a "case study" approach, focusing on one particular option. These considerations suggest that the analysis here concentrate on pricing for Collection and Transportation only.

This restriction facilitates the specification of the supply model for the exploratory analysis here. The review of empirical material in Section IV identifies three elements that determine the cost of collection and haul:

- total amount of solid wastes collected and transported;
- collection frequency;
- pickup density.

For the analysis here, it is permissible to assume that the last two categories have identifiable unit costs that can be covered in the pricing scheme as surcharges.* This assumption leaves the total amount of wastes entering the system as the principal determinant of C&T costs. As the review of the findings of the UC study indicates, the cost function appears to be associated with a production function that it subject to variable returns to scale. If this conclusion is correct, the form of the cost function would be given by:

$$C(u_1) = R(\underline{P}) u_1^{1/\phi(z)}, \quad (14)$$

where $C(u_1)$ = the cost function for the Collection and Transportation subsystems;

* The negative coefficient of collection frequency found in the California study makes it difficult to use these results directly. Additional research would be required to determine the cost impact of increasing the collection frequency, other things being equal.

- $\underline{P}$ = the vector of input prices;
- $R(.)$ = an arbitrary function homogeneous of degree one in input prices;
- u_1 = the total amount of solid waste collected and transported to the processing/disposal site (tons/year);
- $\phi(z)$ = a function describing the behavior of returns to for different population sizes (z).

For a given vector of input prices (wage rates, capital cost), $R(\underline{P})$ is a constant. Possible functional forms for $\phi(z)$ can be specified on the basis of the evidence provided by the UC study. Therefore, the cost function for the C&T subsystem can be determined without great difficulties.

For the exploratory analysis here, it is necessary to determine "direct" SWM services that address that portion of the management system dealing with the self-disposal of wastes. Unfortunately, these components of the SWM system have not been studied in any form sufficient for the specification of functional relationships. The two elements that should be considered are:

- the enforcement of disposal ordinances;
- street cleaning and litter removal.

The enforcement of disposal ordinances is almost impossible to handle. Some attempts have been made by municipalities to employ sanitary inspectors to control for violations of disposal and storage regulations. However, it is impossible to relate employment of inspectors, or cooperation with regular law enforcement agencies to changes in the fine expectations among households. If the output of the system cannot be determined, cost functions become meaningless.

Street cleaning and litter removal also have been studied only insufficiently. The UC study reports a cost of \$45.00 per ton of street waste collected. Gueron [9] mentions a cost per piece of litter of \$0.25 -- which is difficult to relate to total amounts of waste collected. Since no further cost studies of street cleaning and litter removal are available,* the UC figure will be used in the analysis here.

* Data from the 1968 National Survey are insufficient to obtain better estimates; cf. [15].

MODEL SPECIFICATIONS FOR QUANTITATIVE ANALYSIS

The specification of functional relationships, parameter and variable values for the quantitative analysis can only in some circumstances rely on empirical estimates. For the major part, it involves subjective "tuning" to obtain behavioral characteristics that are compatible with actual patterns.

The critical element in the analysis is the specification of the relationships between the parameters of the fine expectation function (μ_F and σ_F) and the fraction of total waste generated that is self-disposed. The net income function given in Equation (10) assumes that the only cost of self-disposal is the expected fine, and the only cost of waste collected is the price charged by the SWM system. This formulation abstracts from a number of issues. For example, there are additional costs to the household of waste collection, such as transportation from the location of consumption to the storage area. The inconveniences associated with transporting litter generated on trips may lead to random littering. Similarly, the time required for preparing garden wastes for storage (shredding of small branches, etc.) may lead to backyard burning. In both cases, the motive for self-disposal is not the charge for collection services, but rather the additional cost of preparing waste for collection. The analysis here abstracts from this possibility, since its main concern is the likely behavior of the household with respect to actions by the SWM system. Random littering of this form could be introduced without great difficulty by assuming a basic value of λ , which fluctuates with a given mean and variance.

Under these restrictive assumptions, which are justified by the main concern of the analysis, the specification of the relationship between the parameters of the fine expectation function and the self-disposal fraction must account for the possibility of some substitution of self-disposal for collection. For example, assume that the price of solid waste collection services is set at \$20 (\$13 for collection, and \$7 for processing and disposal) per ton. Consider a household that generates approximately one ton of solid waste per year; this estimate is low and intended only for illustrative purposes. Assume furthermore that the relationship between μ_F and

λ is linear, i.e. $\mu_F = a \lambda$. The coefficient (a) in this linear relationship depends on fine schedules and enforcement efforts. If it is greater than 20, any self-disposal will result in an expected cost exceeding the user charge that would be collected for all waste generated. Values of a under 20 may result in deviations from the "collect all" decision, depending on the associated risk.

A sample case shown in Table 2 illustrates the pertinent patterns. The values of variables and parameters have been selected for illustration only. For simplicity, risk has been assumed to be constant.* The results of the calculations indicate that the expected net income increases, as the fraction of self-disposal increases. However, in the initial step from no self-disposal to 10% of the total waste self-disposed, the risk factor lowers the expected utility.** Subsequently, expected utility increases with increases in the self-disposal fraction. Under the present set of assumptions, a linear relationship between the expected fine and the self-disposal fraction therefore would lead to "bang-bang" type solutions: as long as the maximum expected fine (for complete self-disposal) exceeds the unit price of collection, all waste will be set up for collection. Once the maximum fine falls short of the unit price of collection, the household is likely to switch to complete self-disposal. The likelihood of a switch depends on the relative risk.

It is possible to obtain alternative results, once the assumption of constant risk is relaxed. As a simple alternative, assume that risk increases linearly with the self-disposal fraction, i.e. $\sigma_F = \sigma_y = b \lambda$. In the example shown in Table 2, some manipulation of the relevant equations indicates that a value of 900 for b , for example, would yield a maximum expected utility at $\lambda = .1$. However, in the case of linear relationships of both the expected fine and the risk to the self-disposal

* The risk is the expected amount by which the fine varies with some probability. At $\lambda = 0$, there is of course no risk.

** The absolute differences in utility for alternative actions (self-disposal fractions shown in Table 2 are extremely small. In interpreting the results, it is important to remember that the utility describes the relative value of available alternatives. An option with a higher utility value is preferred, regardless of the absolute differences.

Table 2. Utilities for Different
Self-Disposal Fractions

λ	μ_F	$\sigma_F = \sigma_y$	μ_y	$U(\mu_y)$	σ_y^2 / μ_y^2	$E(U)$
.0	0.0	-	7,980.0	8.98469	.00000	8.98469
.1	1.5	100	7,980.5	8.98476	.00008	8.98468
.2	3.0	100	7,981.0	8.98482	.00008	8.98474
.3	4.5	100	7,981.5	8.98488	.00008	8.98480
.4	6.0	100	7,982.0	8.98494	.00008	8.98487
.5	7.5	100	7,982.5	8.98501	.00008	8.98493
.6	9.0	100	7,983.0	8.98507	.00008	8.98499
.7	10.5	100	7,983.5	8.98513	.00008	8.98505
.8	12.0	100	7,984.0	8.98519	.00008	8.98512
.9	13.5	100	7,984.5	8.98526	.00008	8.98518
1.0	15.0	100	7,985.0	8.98532	.00008	8.98524

$$E(U) = U(\mu_y) - \sigma_y^2 / \mu_y^2,$$

$$\mu_y = Y - (1 - \lambda) p_C w^* - \mu_F,$$

$$\mu_F = b \lambda.$$

Parameters for sample case: $Y = \$8,000$, $p_C = \$20$, $w^* = 1.0$, $b = 15$,

$$\sigma_y = \sigma_F = 100.$$

fraction, "bang-bang" type solutions are likely: all waste is either collected or self-disposed. Such results appear rather unrealistic.

An alternative specification of the relationships between expected utility and the self-disposal fraction may involve changes of the fine or the risk functions. Given the lack of clarity of the risk concept in the present case, the analysis here focuses on a modification of the fine function. The simplest non-linear relationships between expected fine and the self-disposal fraction is the quadratic one. Table 3 summarizes the results for the same sample case as used in the computations shown in Table 2, with the exception of a quadratic relationship between μ_F and λ , $\mu_F = 30 \lambda^2$. In this particular case, the expected utility initially increases with increasing self-disposal fractions. It reaches a maximum at $\lambda = .3$, and declines subsequently. Under these specifications, the household would self-dispose 30 per cent of the total solid waste generated. The optimal self-disposal fraction is sensitive to the coefficient in the quadratic relationship. Once the coefficient is increased to 70, the optimal self-disposal fraction is much lower, as illustrated in Table 4. For the relationship $\mu_F = 70 \lambda^2$, the optimal fraction is .1.

Under the assumption of a non-linear relationship between expected fine and the self-disposal fraction, the determination of an optimal self-disposal fraction no longer requires the specification of discrete actions (stepped values of λ). The optimal self-disposal fraction can be obtained by differentiating the expected utility with respect to λ . From Equation (11), we have

$$E(U) = U(\mu_y) - \frac{\sigma_y^2}{2\mu_y^2},$$

$$\text{where } \mu_y = Y - (1 - \lambda)p_C w^* - \mu_F,$$

$$\text{and } \sigma_y = \sigma_F = \text{constant}.$$

Differentiation of this expression with respect to λ yields the condition for a maximum:

$$\frac{d E(U)}{d \lambda} = \left[\frac{1}{\mu_y} + \frac{\sigma_y^2}{\mu_y^3} \right] [p_C w^* - \frac{d \mu_F}{d \lambda}] = 0.$$

Table 3. Utilities for Different
Self-Disposal Fractions

λ	μ_F	$\sigma_F = \sigma_y$	μ_y	$U(\mu_y)$	σ_y^2 / μ_y^2	$E(U)$
.0	0.00	-	7,980.00	8.98469	.00000	8.98469
.1	0.30	100	7,981.70	8.98491	.00008	8.98483
.2	1.20	100	7,982.80	8.98504	.00008	8.98496
.3	2.70	100	7,983.30	8.98511	.00008	8.98503
.4	4.80	100	7,983.20	8.98509	.00008	8.98501
.5	7.50	100	7,982.50	8.98501	.00008	8.98493
.6	10.80	100	7,981.20	8.98484	.00008	8.98476
.7	14.70	100	7,979.30	8.98461	.00008	8.98453
.8	19.20	100	7,976.80	8.98429	.00008	8.98421
.9	24.30	100	7,973.70	8.98390	.00008	8.98382
1.0	30.00	100	7,970.00	8.98344	.00008	8.98336

Specifications: Same as in Table 2, except for $\mu_F = 30 \lambda^2$.

Table 4. Utilities for Different
Self-Disposal Fractions

λ	μ_F	$\sigma_F = \sigma_y$	μ_y	$U(\mu_y)$	σ_y^2 / μ_y^2	$E(U)$
.0	0.00	-	7,980.00	8.98469	.00000	8.98469
.1	0.70	100	7,981.30	8.98486	.00008	8.98478
.2	2.80	100	7,981.20	8.98484	.00008	8.98476
.3	6.30	100	7,979.70	8.98466	.00008	8.98458
.4	11.20	100	7,976.80	8.98429	.00008	8.98421
.5	17.50	100	7,972.50	8.98375	.00008	8.98367
.6	25.20	100	7,966.80	8.98304	.00008	8.98296
.7	34.30	100	7,959.70	8.98215	.00008	8.98207
.8	44.80	100	7,951.20	8.98108	.00008	8.98100
.9	56.70	100	7,941.30	8.97983	.00008	8.97975
1.0	70.00	100	7,930.00	8.97841	.00008	8.97833

Specifications: Same as in Table 2, except for $\mu_F = 70 \lambda^2$.

Since the first term in this expression is a positive factor, we obtain the condition that the self-disposal fraction will be chosen such that the derivative of the expected fine function is equal to the total cost of having all waste collected:

$$p_C^{w*} = \frac{d\mu_F}{d\lambda} \quad (15)$$

In the case of a quadratic relationship between the expected fine and the self-disposal fraction, $\mu_F = a\lambda^2$, we obtain the expression for λ that maximizes the expected utility: $\lambda = p_C^{w*}/2b$. This expression illustrates that the SWM decision maker can use the pricing of collection services as well as manipulation of the factors that influence the fine expectations to control the degree of self-disposal in the community.

The analysis of the decision-theoretic model concerning the choice between self-disposal and collection thus allows for a straightforward determination of the impact of pricing on self-disposal/collection patterns. It is interesting to note that the present formulation does not require information on the income level of the household in question (except indirectly, through its effect on the amount of waste generated). It should also be noted that the present formulation has been simplified by assuming that the risk does not vary with the self-disposal fraction. This assumption could be relaxed without great difficulty. Aside from this particular constraint, the decision-theoretic model results offer a flexible means of determining the impact of pricing collection services on total system costs. They also establish a basis for deriving an approximate waste generation function which can be used to illustrate the impact numerically.

The evidence reported in the Chicago study indicates that the elasticity of waste generation with respect to income is less than unity (under the assumption that relationships observed between income and waste collected can be treated as representative of the generation function). Given the variability of the actual coefficients, the sample calculations here use a value of the elasticity of generation of .5. The UC study, in turn, at least suggests an inverse relationship between the marginal cost of

transferring solid waste from the private to the public domain (the composite "price" of waste generation). Since there exists no empirical guide, the analysis of the relative impact of alternative pricing schemes assumes an elasticity of $-.5$. The justification for choosing this value is primarily computational convenience.

The waste generation function used is of the multiplicative form, which implies a constant elasticity of waste generation with respect to both income and marginal cost:

$$w^* = A Y^{.5} p^{*-}.5 \quad (16)$$

where A = a proportionality constant; the experimentation with relevant values of Y and p_C indicated that $A = .025$ would generate values of w^* (in tons) that largely corresponded to empirically determined ranges;
 p^* = the marginal cost of waste generation.

The exact expression for p^* can be derived from the general cost function and the optimality condition for λ . The general cost equation is given by

$$C = p_C (1 - \lambda) w^* + \mu_F(\lambda).$$

Under the assumption that the expected fine is independent of the amount of waste generated (or self-disposed), the marginal cost p^* is given by

$$p^* = p_C(1 - \lambda) = p_C(1 - p_C w^*/2b),$$

after substituting the optimality condition for the quadratic fine function. In the numerical analysis, b has been assumed to be equal to 50.

With these specifications, Equation (16) can be used to compute the total waste generated and its allocation between collection and self-disposal, as well as the implications of alternative patterns for total system costs. Several sample cases are presented in Table 5. The figures shown

Table 5. Optimal Waste Generation and Allocation Patterns,
Sample Cases

Y	PC	1	21	41
3,000		$w^* = 1.38$ $\lambda = .014$ $C_1 = \$13.45$ $C_2 = \$18.56$	$w^* = .309$ $\lambda = .065$ $C_1 = \$15.09$ $C_2 = \$4.66$	$w^* = .224$ $\lambda = .092$ $C_1 = \$15.94$ $C_2 = \$3.57$
8,000		$w^* = 2.26$ $\lambda = .023$ $C_1 = \$13.74$ $C_2 = \$31.05$	$w^* = .517$ $\lambda = .109$ $C_1 = \$16.49$ $C_2 = \$8.53$	$w^* = .380$ $\lambda = .156$ $C_1 = \$17.99$ $C_2 = \$6.84$
13,000		$w^* = 2.89$ $\lambda = .029$ $C_1 = \$13.93$ $C_2 = \$40.26$	$w^* = .671$ $\lambda = .141$ $C_1 = \$17.52$ $C_2 = \$11.76$	$w^* = .499$ $\lambda = .205$ $C_1 = \$19.57$ $C_2 = \$9.77$
18,000		$w^* = 3.41$ $\lambda = .034$ $C_1 = \$14.09$ $C_2 = \$48.05$	$w^* = .803$ $\lambda = .169$ $C_1 = \$18.41$ $C_2 = \$14.78$	$w^* = .604$ $\lambda = .248$ $C_1 = \$20.94$ $C_2 = \$12.65$

$$w^* = \text{Solution to } w^* = .025 Y^5 (1 - pcw^*/2b) PC^{-.5}$$

$$\lambda = pcw^*/2b$$

$$C_1 = (\$45) + (1 -) (\$13)$$

$$C_2 = w^* \cdot C_1$$

use the cost estimates reported in the UC study: \$13 per ton for collection, and \$45 per ton picked up as litter in the public domain. The results for this sample case indicate that the increase in the percentage littered that accompanies an increase in the price of collection results in higher costs per ton handled. However, the smaller amounts of waste generated lower the cost per household.

While these results are only illustrative, they suggest that -- provided a relevant parameter configuration -- pricing in solid waste management systems may in fact improve the overall efficiency of resource utilization by reducing the amount of solid waste generated and thereby SWM costs per household. These assessments are clearly exploratory in nature. Even so, the results of the numerical examples are encouraging in the sense that pricing of SWM collection services may become a useful management tool, resulting in lower cost as well as resource conservation. A definitive conclusion is of course impossible as long as reliable empirical information is unavailable.

SUMMARY

The analysis in this section develops a comprehensive model for examining the impact of pricing in solid waste management systems, defined in a more comprehensive sense as including the pickup and processing of self-disposed wastes. To the extent possible, the components of the model are extracted from available empirical evidence. The resulting model is conceptually simple. It is suitable for easy modification and adaptation to a particular situation, or an improved empirical data base. Thus, it can serve to clarify in -- admittedly crude -- numerical form some of the issues that surround the pricing of collection services in solid waste management systems.

The application of the model in a "quasi-empirical" analysis yields acceptable results in terms of the total amount of solid waste generated per household, as well as the distribution between collection and self-disposal. The specific estimates may be on the low side, but they are sufficient to indicate that the radical switch from collection to self-

disposal that has been suggested in the literature as the likely result of the explicit pricing of SWM services may not occur. In fact, in the numerical sample cases examined, the analysis suggests that there would be social benefits in terms of lower costs of solid waste handling (as well as resource conservation), even after an appropriate allowance for increased expenditures on street cleaning and litter pickup.

Given the dearth of empirical data, the analysis here cannot provide definitive answers. But the conceptual framework that has been developed in this context can serve as a basis for further research.

SECTION VII

ASSESSMENT OF THE FEASIBILITY OF SWM PRICING MECHANISMS

Throughout the discussion in this report, we have assumed that it is possible to implement a pricing scheme that would charge individual households in relation to the amount of (weight) of solid waste that is being collected by the SWM system. This assumption is clearly an oversimplification. Charging on the basis of weight of refuse is practically impossible, unless some specific technical obstacles can be overcome. In addition, there would be the problem of implementing a pricing mechanism that would provide the appropriate incentives for facilitating pickup, source separation of certain types of wastes, and similar aspects.

Given the present technology, the type of user charges levied on the basis of the number and size of containers used by the household constitutes probably the closest approximation to an effective pricing mechanism that would fulfill its signal function. It is by no means perfect, since charges refer to storage capacity rather than utilization. For a given number of cans, there would be no incentive to the household to reduce the generation of solid waste. Even so, the evidence of the UC study indicates that such user charges do affect the behavior of the household, if not with respect to waste generation, so at least with respect to self-disposal.

Another approach, which has been tested experimentally, combines the administrative ease of user charges based on container capacity with an allowance for capacity utilization. The implementation of this approach would correspond in principle to a prepayment plan. The household is responsible for purchasing at some point in time the right to X units of solid waste collection services. This stock of service rights is depleted as services are being consumed.

The application of this concept requires some provision for assuring the depletion of the stock of service rights. Perhaps the simplest way would

be the sale of a special type of throwaway container (e.g. a plastic bag). Any waste not in such a container would not be picked up by the collection crew. For bulky items, stickers could be used to indicate payment; such stickers or tags could also be used to "convert" existing containers.

One additional advantage of such a scheme would be its potential for encouraging source separation. For example, containers (or tags) for separated materials such as paper, glass, metals could be sold at a lower rate, thus providing a direct and effective incentive to follow such practices.

There are of course a number of administrative problems with this approach as well. For example, any enforcement of such a regulation would be likely to encourage self-disposal, since it introduces an additional inconvenience involved in picking up the containers (or tags). This problem could be minimized by establishing an adequate distribution network (e.g. sale of collection rights in supermarkets). In addition, though, there is a psychological element which could be described as resistance against being forced into certain behavior patterns (using normed containers). The introduction of such an approach therefore may require substantial public information efforts.

To what extent such problems could nullify the potential effectiveness of such a "prepayment plan" for collection services cannot be stated with certainty. In any case, the approach appears administratively feasible. If the results of the exploratory analysis in the preceding section are in fact indicative of the potential of pricing mechanisms in SWM systems, the practical approach suggested here should be tried in the form of an organized experiment in a number of communities.

SECTION VIII

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APPENDIX A
PRICING UNDER EQUILIBRIUM CONDITIONS

THE BASIC MODEL

The approach used here to determine pricing rules for solid waste management under optimality conditions rests on a social welfare function of the type described in standard textbooks, such as Henderson and Quandt [pp. 217-222]. This social welfare function is some aggregate expression of individual utility functions. Let U_j denote the utility level of the j -th consumer ($j = 1, \dots, N$).^{*} Then the social welfare function can be written as

$$\bar{U} = \bar{U}(U_1, \dots, U_N) \quad (1)$$

The individual utility functions appearing as arguments in this social welfare function depend in part on the amount of solid waste discharged into the environment. This discharge can assume either one of two forms: (1) disposal at a socially selected disposal site, generally through collection; and (2) disposal in other parts of the environment, through littering, dumping, on-site burning, and other socially undesirable disposal methods. This interpretation suggests that there are two "classes" of environmental resource: areas that have little social utility per se, and are therefore suitable as disposal sites (generally landfill areas). The other "class" of environment is more valuable; disposal in this environment involves high costs.

We assume that these social costs are borne only by consumers. The two methods of solid waste disposal therefore give rise to two types of *consumption externalities*. The determination of optimal pricing rules would of course be easier if the analysis could be restricted to production externalities. In that case, the effects of solid waste generation and disposal could be expressed directly in dollar terms. Unfortunately, this convenient restriction, which is quite common in the literature on externalities, is difficult to maintain in the present context. The principal impact of solid waste disposal is on the consumer. Therefore, the analysis here will deal only with the consumption aspect.

^{*}The notation here differs from that used in the main body of the report.

On the basis of these considerations, the utility function of the j -th consumer can now be written as:

$$U_j = U_j(y^j, w_1, w_2), \quad (j = 1, \dots, N) \quad (2)$$

where $y^j = \{y_i^j\}$, ($i = 1, \dots, M$) denotes the vector of the M goods and services consumed by the j -th household. The w_i denote the total amounts of solid waste discharged into the environment in the two categories; w_1 is the total amount of solid waste disposed of in "proper form", while w_2 denotes the total amount littered or dumped.

The solid waste generation function for the j -th consumer is derived on the basis of the assumption that consumption as such contributes to the total solid waste "produced". In effect, we have a joint consumption/waste generation model, analogous to Whitcomb's generalized joint production function. The total amount of solid waste generated by the j -th consumer is either put up for collection or littered. Let v_{1j}^C denote the amount put into some container for collection, and v_{2j}^C the amount littered.* Then we can write the solid waste generation function for the j -th consumer as:

$$\sum_{\ell=1}^2 v_{\ell j}^C = H_j(y^j) \quad (j = 1, \dots, N) \quad (3)$$

This general specification of the consumer's solid waste generation function as an expression in the M components of the y^j vector is sufficiently flexible to handle a variety of possibilities. For example, it is entirely possible that some of the M goods actually contribute to a reduction of the total waste volume, such as garbage disposals, trash compactors, glass cutters for the reuse of bottles, etc.

The production of the M goods and services is determined by the production functions:

$$\sum_{j=1}^N y_i^j = F_i(x^i), \quad (i = 1, \dots, M) \quad (4)$$

where $x^i = \{x_k^i\}$, ($k = 1, \dots, K$) denotes the vector of the K factor inputs

* All amounts are measured over some unit time period, say, a year.

used in the production of the i -th good. This production function reflects the assumption that there are no production externalities associated with solid waste disposal. Assume that each good is produced by one firm.

The solid waste generation function for the i -th producer is derived on the basis of the assumptions used in the case of the consumer. The joint production/generation model used by Whitcomb [20] has been simplified by restricting it to purely "joint" inputs. Thus, we have the solid waste generation function for the i -th producer:

$$\sum_{\ell=1}^2 v_{\ell i}^P = G_i(x^i), \quad (i = 1, \dots, M) \quad (5)$$

where v_{1i}^P = the amount of solid waste collected from the i -th producer;

v_{2i}^P = the amount of solid waste "littered" by the i -th producer.

Strictly speaking, the case of ordinary inputs that appear in only $F_i(\cdot)$ or $G_i(\cdot)$ could easily be handled by setting its partial derivative in either function equal to zero. In that manner, the present formulation could account for resource recovery activities on the part of the individual firm. However, the analysis here will neglect such possibilities.

Equations (2) to (5) describe the basic microeconomic characteristics of the system. The link between the total solid waste generated by consumers and producers and the two types of solid waste externalities appearing in the individual utility functions (2) is established by the social activities of solid waste collection and litter removal. Solid waste collection activities are assumed here to include the collection of solid waste, transportation, processing (including resource recovery activities), and final disposal at an "authorized" disposal site. The social activity of litter removal differs from collection primarily in the sense that pickup is more costly; otherwise, it includes the same activities.

On the basis of these assumptions, the total amount of solid waste properly disposed of is given by:

$$w_1 = F_S(x^S, \sum_j v_{2j}^C + \sum_i v_{1i}^P) + F_L(x^L, \sum_j v_{2j}^C + \sum_i v_{2i}^P), \quad (6)$$

The solid waste that remains as litter in the environment can then simply be expressed as a residual:

$$w_2 = \sum_j v_{2j}^C + \sum_i v_{2i}^P - F_L(.) \quad (7)$$

The x^X and x^L in equations (6) and (7) denote the vector of factor inputs used in the two social activities related to solid waste.

Finally, assume that the total resource endowment of the economy is given by a set of resource constraints:

$$\bar{x}_k = \sum_i x_k^i + x_k^S + x_k^L, \quad (k = 1, \dots, K)$$

Equations (1) to (8) completely describe the framework for determining optimal pricing rules for solid waste management under equilibrium conditions.

DETERMINATION OF SOCIAL OPTIMALITY CONDITIONS

The conditions for a social optimum refer to the values of all variables in the system. They can be derived by maximizing social utility $\bar{U}$ subject to the constraints stated in equations (2) to (8). We therefore form the Lagrangian:

$$\begin{aligned} Q = \bar{U} &+ \sum_i \lambda_i \left[\sum_j y_i^j - F_i(x^i) \right] \\ &+ \sum_i \mu_i \left[\sum_l v_{li}^P - G_i(x^i) \right] \\ &+ \sum_j \eta_j \left[\sum_l v_{lj}^P - H_j(y^j) \right] \\ &+ \xi \left[w_1 - F_S(x^S, \sum_i v_{1i}^P + \sum_j v_{1j}^C) \right. \\ &\quad \left. - F_L(x^L, v_{2i}^P + \sum_j v_{2j}^C) \right] \\ &+ \zeta \left[w_2 - \sum_i v_{2i}^P - \sum_j v_{2j}^C + F_L(x^L, \sum_i v_{2i}^P + \sum_j v_{2j}^C) \right] \\ &+ \sum_k \gamma_k \left[\bar{x}_k - \sum_i x_k^i - x_k^S - x_k^L \right] \end{aligned} \quad (8)$$

The first-order conditions for social optimality are found by taking the derivatives of Q with respect to all variables in the system and setting them equal to zero. This procedure yields the following set of equations:

$$\frac{\partial Q}{\partial y_i^j} = \frac{\partial \bar{U}}{\partial y_i^j} + \lambda_i - \eta_j \frac{\partial H_j}{\partial y_i^j} = 0 \quad (9)$$

$$\frac{\partial Q}{\partial x_k^i} = -\lambda_i \frac{F_i}{\partial x_k^i} - \mu_i \frac{G_i}{\partial x_k^i} - \gamma_k = 0 \quad (10)$$

$$\frac{\partial Q}{\partial x_k^S} = -\xi \frac{\partial F_S}{\partial x_k^S} - \gamma_k = 0 \quad (11)$$

$$\frac{\partial Q}{\partial x_k^L} = -\xi \frac{\partial F_L}{\partial x_k^L} + \zeta \frac{\partial F_L}{\partial x_k^L} - \gamma_k = 0 \quad (12)$$

$$\frac{\partial Q}{\partial v_{1i}^P} = \mu_i - \xi \frac{\partial F_S}{\partial v_{1i}^P} = 0 \quad (13)$$

$$\frac{\partial Q}{\partial v_{1j}^C} = \eta_j - \xi \frac{\partial F_S}{\partial v_{1j}^C} = 0 \quad (14)$$

$$\frac{\partial Q}{\partial v_{2i}^P} = \mu_i - \xi \frac{\partial F_L}{\partial v_{2i}^P} + \zeta \left[\frac{\partial F_L}{\partial v_{2i}^P} - 1 \right] = 0 \quad (15)$$

$$\frac{\partial Q}{\partial v_{2j}^C} = \eta_j - \xi \frac{\partial F_L}{\partial v_{2j}^C} + \zeta \left[\frac{\partial F_L}{\partial v_{2j}^C} - 1 \right] = 0 \quad (16)$$

$$\frac{\partial Q}{\partial w_1} = \frac{\partial \bar{U}}{\partial w_1} + \xi = 0 \quad (17)$$

$$\frac{\partial Q}{\partial w_2} = \frac{\partial \bar{U}}{\partial w_2} + \zeta = 0 \quad (18)$$

$$\frac{\partial Q}{\partial \lambda_i} = \sum_j y_i^j - F_i(x^i) = 0 \quad (19)$$

$$\frac{\partial Q}{\partial \mu_i} = \sum_l v_{li}^P - G_i(x^i) = 0 \quad (20)$$

$$\frac{\partial Q}{\partial \eta_j} = \sum_l v_{lj}^C - H_j(y^j) = 0 \quad (21)$$

$$\frac{\partial Q}{\partial \xi} = w_1 - F_s(.) - F_L(.) = 0 \quad (22)$$

$$\frac{\partial Q}{\partial \zeta} = w_2 - \sum_i v_{2i}^P - \sum_j v_{2j}^C + F_L(.) = 0 \quad (23)$$

$$\frac{\partial Q}{\partial \gamma_k} = \bar{w}_k - \sum_k x_k^i - x_k^S - x_k^L \quad (24)$$

Under the assumption that the second-order conditions are satisfied (which depends on the concavity of the utility and production functions in the system), these conditions can now be solved for the values of the variables in the optimal situation. However, these conditions reflect a specific resource endowment. Optimality conditions that hold for any given resource level are required. These conditions can be found by simply dropping the resource constraint set (13). However, the Lagrangean multipliers are likely to reflect the specific resource endowment. These multipliers must therefore be eliminated.

Since the Lagrangean multiplier can be interpreted as the shadow prices of the constraints, their specifications are needed in deriving optimal pricing rules. Through successive elimination, we obtain the following expressions for these multipliers:

$$\lambda_i = - \frac{\partial \bar{U}}{\partial w_1} \cdot \frac{\partial F_S}{\partial v_{1j}^C} \cdot \frac{\partial H_j}{\partial y_1^j} - \frac{\partial \bar{U}}{\partial y_1^j} \quad (25)$$

$$\mu_i = - \frac{\partial \bar{U}}{\partial w_1} \cdot \frac{\partial F_S}{\partial v_{11}^P} \quad (26)$$

$$\eta_j = - \frac{\partial \bar{U}}{\partial w_1} \cdot \frac{\partial F_S}{\partial v_{1j}^C} \quad (27)$$

$$\xi = - \frac{\partial \bar{U}}{\partial w_1} \quad (28)$$

$$\zeta = - \frac{\partial \bar{U}}{\partial w_2} \quad (29)$$

$$\gamma_k = - \frac{\partial \bar{U}}{\partial w_1} \cdot \frac{\partial F_S}{\partial x_k^S} \quad (30)$$

These expressions for the Lagrangean multipliers as shadow prices for the associated constraints have some intuitive appeal. For example, ξ is the shadow price of the "lower-class" environmental resource, expressed as the disutility of solid waste disposed of at approved disposal sites. The solutions for the multipliers given in Equations (25) to (30) can now be used to derive general conditions for a social optimum. However, these equilibrium conditions are insufficient for determining optimal pricing rules in solid waste management, since appropriate allocation of resources to the SWM system presumes that all other resources are optimally employed. The pricing rules that could be derived from these conditions therefore fail to provide the required policy information concerning the pricing strategies to reach (or at least approach) the optimum. The general equilibrium framework therefore does not lead to the desired solutions.

APPENDIX B

THE MATHEMATICS OF THE DECISION-THEORETIC APPROACH

This appendix briefly summarizes the salient elements of the decision-theoretic model used in determining the allocation of solid waste to collection and self-disposal. The core of the decision-theoretic approach is the conditional cost-of-self-disposal expectation for a given fraction of solid waste going to self-disposal. However, the decision analysis does not require a specification of the functional form of the expectation function. Only two parameters, the mean and the variance for different levels of λ , the self-disposal fraction.

The substantive characteristics of the decision-theoretic approach have been described in greater detail in the body of the text. The focus here is on the derivation of Equation (11), which constitutes the basis for the simplified decision analysis.

Consider utility as some function of net income, $U(y)$. This function can be written in form of a Taylor series expansion as a function of powers of $(y - c)$, where c is some constant:

$$U(y) = \sum_{n=0}^{\infty} \frac{(y - c)^n}{n!} \frac{d^{(n)}U(c)}{dy^n}.$$

If the arbitrary constant in this expression, c , is set equal to μ_y , the expected net income for the given self-disposal fraction, the Taylor series expansion becomes:

$$U(y) = \sum_{n=0}^{\infty} \frac{(y - \mu_y)^n}{n!} \frac{d^{(n)}U(\mu_y)}{dy^n}$$

Taking expected values on both sides of the equation yields the expected utility as a function of the moments of the net income expectation function and the derivatives of the utility function, evaluated at μ_y :

$$E[U(y)] = \sum_{n=0}^{\infty} \frac{E[(y - \mu_y)^n]}{n!} \frac{d^{(n)}U(\mu_y)}{dy^n}$$

It is common practice to regard only the first three terms on the right-hand side of the expression as significant ($n = 0, 1, 2$).

Under the assumption of risk-averse behavior, an appropriate specification of the utility function is the logarithmic form, $U = \ln(y)$. For this specification, the expected utilities for each level of the self-disposal fraction can be obtained; dropping all terms in the sum for $n > 2$, we obtain for the logarithmic utility function:

$$\begin{aligned} E[U(y)] &= U(\mu_y) + \frac{\sigma_y^2}{2} \frac{d^2 U(\mu_y)}{dy^2} \\ &= U(\mu_y) - \frac{1}{2} [\sigma_y / \mu_y]^2 \end{aligned}$$

APPENDIX C

REGRESSION ANALYSIS OF CHICAGO DATA

The Chicago study [4] relies heavily on the relative performance of alternative model specifications in a linear regression analysis. The authors correctly identify the problem of heteroscedasticity associated with the fact that only part of the total residential waste in each of the political wards of the Chicago metropolitan area is collected by the municipal system. However, the weighting procedure designed to correct for this problem is not derived from a clear understanding of the nature and sources of heteroscedasticity in this particular situation.

Briefly, heteroscedasticity refers to case in which the individual observations used in the analysis cannot be assumed to have been drawn from the same population with a given mean and standard deviation. In cases in which averages are being used to describe subsets of basic units of observations (e.g. households), it can be assumed that the expected value or mean for each group is the same as the population mean. However, the standard deviation of the i -th average is known to be (on the basis of the Central Limit Theorem) $\sigma/\sqrt{n_i}$, where σ is the population standard deviation and n_i is the number of observations used in computing the i -th average.

In order to remove this known source of heteroscedasticity from the observations, all observations can be standardized so that their standard deviation is equal to the population standard deviation. This objective can be achieved by multiplying each observation by a factor equal to $\sqrt{n_i}$. This procedure will result in a standard deviation of $\sqrt{n_i} (\sigma/\sqrt{n_i}) = \sigma$. (For a derivation of this weighting procedure in the framework of Generalized Least Squares, see Note at the end of this appendix.)

The problem is further complicated in the case of the Chicago study by the fact that the underlying units of observation vary for different variables. For example, for average household size and median family income, it is the total number of households that forms the basis for

the computation of these statistics. For the average wasteload collected per household, the relevant figure is the number of households serviced. These considerations lead to the conclusion that the appropriate redefinition of the original variables is as follows:

$$D'_i = D_i \cdot \sqrt{P_i \cdot f_i / S_i}$$

$$Y'_i = Y_i \cdot \sqrt{P_i / S_i}$$

$$S'_i = S_i \cdot \sqrt{P_i / S_i}$$

where D_i = amount of solid waste collected per dwelling unit in ward i ;

Y_i = median family income for ward i ;

S_i = average household size for ward i ;

f_i = fraction of households municipally served;

P_i = total population residing in ward i (such that P_i / S_i = number of households in ward i).

In addition to examining the effects of these alternative weights on the performance of the regression equation, this note is also concerned with the analysis of the possibility of interaction effects between household size and income. These interaction effects can be captured by introducing the product of the two variables as an independent variable into the equation. The rationale for this procedure is similar to that used in introducing multiplicative dummy variables; the coefficient of the product indicates the conditional effect of either variable.

The Chicago study found a significant relationship between household size and the amount of waste collected only for week 32. The regression equations reported are:

$$1968: \quad D_i = 12.10 + \underline{.00203} Y_i + \underline{9.82} S_i \quad R^2 = .2877$$

$$1969: \quad D_i = 9.26 + \underline{.00309} Y_i + \underline{8.42} S_i \quad R^2 = .3373$$

The underlining of regression coefficients implies that they are significant at the 95% confidence level.

These results are presumably based on regression runs using data weighted by f_1^2 . For the examination of the possibility of income-size interaction effects, we have used data for weeks 32 and 21 for the two years. As a check, the regression equations without interaction effects were rerun, with each observation weighted by f_1^2 . The results of these regression runs in no way corresponded to the findings reported in the Chicago study:

Week 21

$$1968: D_i = -.517 + .00467 Y_i + 5.986 S_i \quad R^2 = .951$$

$$1969: D_i = -.206 + .00425 Y_i + 7.886 S_i \quad R^2 = .948$$

Week 32

$$1968: D_i = .740 + .00315 Y_i + 9.971 S_i \quad R^2 = .935$$

$$1969: D_i = .779 + .00398 Y_i + 8.284 S_i \quad R^2 = .937$$

The explanatory power of these equations is much higher than those reported in the Chicago study. In an attempt to replicate the findings of the Chicago study, another equation was run, using the f_1^2 -weights only for the dependent variables. These results failed to correspond to the ones reported as well:

Week 21

$$1968: D_i = -104.5 + .00932 Y_i + 20.12 S_i \quad R^2 = .6779$$

$$1969: D_i = -107.1 + .00937 Y_i + 21.36 S_i \quad R^2 = .6617$$

Week 32

$$1968: D_i = -99.9 + .00847 Y_i + 21.14 S_i \quad R^2 = .6377$$

$$1969: D_i = -105.7 + .00917 Y_i + 21.58 S_i \quad R^2 = .6608$$

Again, the performance of this specification is considerably better than that reported in the Chicago study. Given the available information, we cannot determine the reasons for the discrepancies.

The regression equation without the interaction component using the weights

described above performed better than the unweighted regressions, but not as well as the ones in which all observations and variables had been weighted by f_i^2 (our regression analysis results):

Week 21

$$1968: D_i = -6608.29 + .00454 Y_i + 17.64 S_i \quad R^2 = .711$$

$$1969: D_i = -6818.79 + .00414 Y_i + 20.00 S_i \quad R^2 = .667$$

Week 32

$$1968: D_i = -5225.62 + .00325 Y_i + 18.61 S_i \quad R^2 = .592$$

$$1969: D_i = -6234.83 + .00392 Y_i + 19.59 S_i \quad R^2 = .640$$

The performance of these equations is satisfactory for both weeks; the weighting of the variables has a sounder theoretical base. Therefore, it is reasonable to expect that household size is a significant factor in explaining the average wasteload collected per residential unit.

A theoretical analysis of the likely nature of any interaction effects between household size and income suggests that the coefficient of the product of these two variables, describing the conditional impact of each, given a certain level of the other, should be negative. As income increases, the marginal effect of household size on consumption and waste generation decreases. Similarly, the marginal effect of income is likely to decrease with increasing household size. In the expression

$$D_i = a_0 + a_1 Y_i + a_2 S_i + a_3 (Y_i \cdot S_i),$$

the marginal effect of, say, household size is given by:

$$\frac{dD_i}{dY_i} = a_2 + a_3 Y_i$$

If the marginal impact of size decreases with increasing income levels, a_3 should be negative.

The introduction of the interaction term (product of income and household size) into the regression equations improved their performance marginally,

as indicated by slightly higher multiple correlation coefficients. However, none of the variables were significant. Therefore, the hypothesis of an interaction effect between income level and household size must be rejected.

NOTE: THE WEIGHTING PROCEDURE IN THE CONTEXT OF GENERALIZED LEAST SQUARES

The following exposition is based on Theil [19, pp. 237-44]. Consider the standard linear model $y = X\beta + \epsilon$, where y is the vector of dependent observations, X the matrix of independent variables, β the coefficient vector, and ϵ the vector of disturbances. Assume now that the conditional variance-covariance matrix of y given X is

$$(y|X) = \sigma^2 V,$$

where σ^2 is an unknown positive parameter and V is a known symmetric positive definite $n \times n$ matrix whose trace is equal to n .

Since usual regression procedures assume that V is the identity matrix, the simplest way to find an estimator that is best is by transforming the observation matrix $[y \ X]$ so that the variance-covariance matrix after the transformation is $\sigma^2 I$ rather than $\sigma^2 V$. Since V is symmetric and positive definite, so is V^{-1} . There exists a non-singular $n \times n$ matrix P such that $P'P = V^{-1}$. Premultiplying both sides of $y = X\beta + \epsilon$ by P yields

$$Py = P X \beta + P \epsilon$$

The new observation matrix is thus $[Py \ PX]$. The variance-covariance matrix of the new disturbance vector $P\epsilon$ -- which continues to have a zero expectation -- is then given by

$$(P\epsilon) = P (\epsilon\epsilon') P' = \sigma^2 PVP' = \sigma^2 P(P'P)^{-1}P' = \sigma^2 I.$$

Under the assumption of independence among observations (i.e. all covariances being zero), the original variance-covariance matrix for a set of observations consisting of means for groups rather than individual units is a diagonal matrix with the typical element $1/n_i$ (by the Central Limit Theorem), where n_i is the number of elements in the i -th group. The typical element of V^{-1}

is therefore n_i , which in turn yields a matrix P which is also diagonal with typical element $\sqrt{n_i}$. Hence, in the case of a regression analysis based on group averages, we obtain the variance-covariance matrix $\sigma^2 I$ (which is a necessary condition for best estimators) by simply multiplying all observations by $\sqrt{n_i}$.